THE SOIL AND CROP SCIENCE SOCIETY OF FLORIDA

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Twentieth Annual Meeting of the Society
Fort Harrison Hotel
Clearwater, Florida

November 28, 29 and 30, 1960

OFFICERS OF THE SOCIETY

1961

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Retiring Officers listed on page 428

CONTENTS

CONTENTS (Cont'd)

ACKNOWLEDGMENTS

It is the desire of the Executive Committee to express its sincere thanks to the Manager of Hotel Fort Harrison, Clearwater, and his staff for the fine manner in which they took care of the needs and comfort of all in attendance upon the annual meeting; also to the efficient staff of the Convention Bureau of the Clearwater Chamber of Commerce, for their splendid assistance with registration and many other details in the same cause.

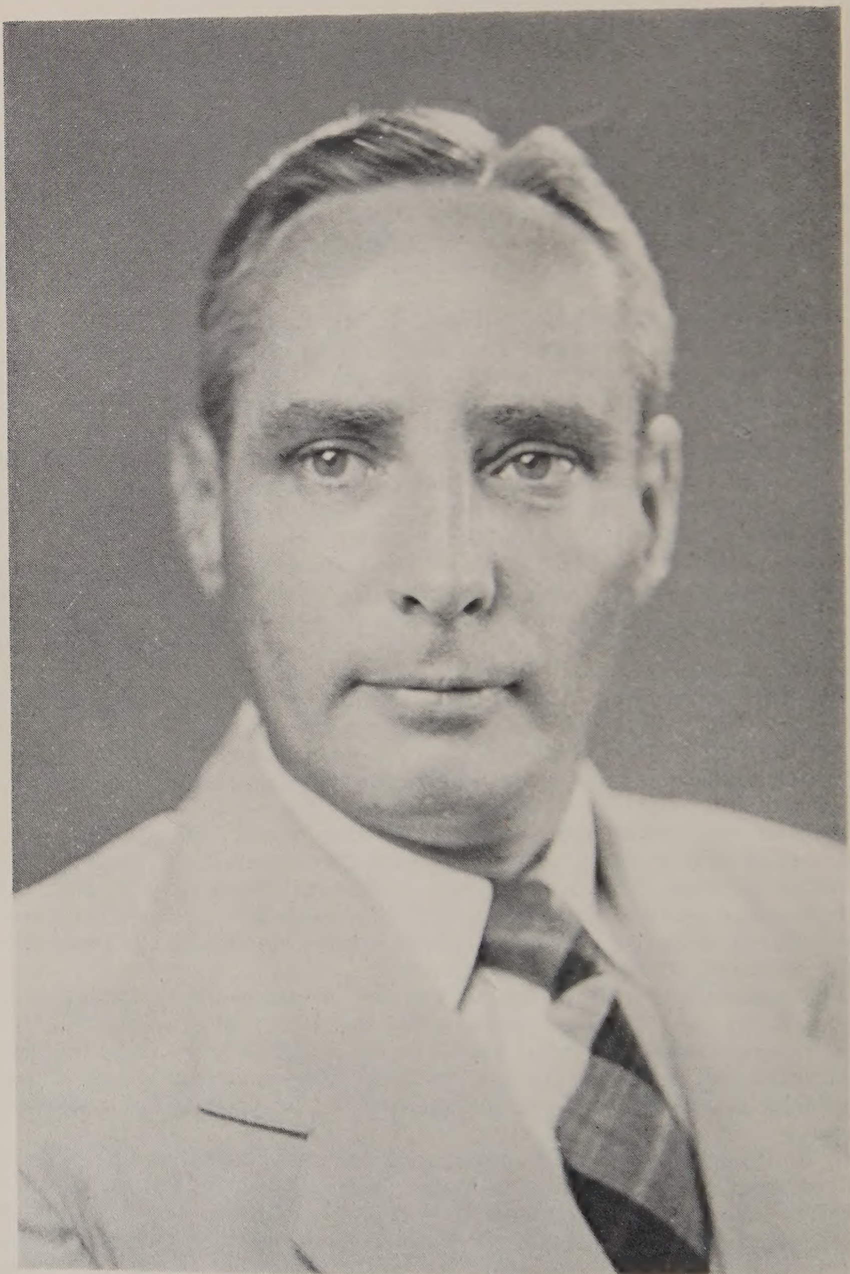
Our particular thanks are extended to Mr. G. E. Dail, Jr. and the staff of the Central and Southern Florida Flood Control District, along with other workers who were invited to take part, for the thorough manner in which they developed a symposium report on all phases of the organization and operation of that great district which is proving so effective not only in its physical relationships with the use of the land but as an efficiently cooperative administrative unit in the accomplishment of public good far in excess of its actual cost as a result of truly cooperative effort on the part of federal, state and local governments.

It is a particular pleasure again to thank Dr. George D. Scarseth for the special effort which we know he made to be with us again this year and especially for his brief but pointed after-dinner address on "The High Road to Crop Production." George has long since become one of the most ardent supporters of what he now consistently refers to as "our" Society with a boundlessness of enthusiasm which all but requires a reworking of Mr. Robert Hooke's well-known law of elasticity.

At the time of this, our twentieth annual meeting, we again acknowledge with thanks borne of deep humility acceptance of the Society's selection of ten internationally known scientists in the field of soils and crops, each in or near retirement. This additional number brings this group to a total of twenty which we shall be proud to maintain at this level thru the years to come. May we take this opportunity also to wish each one of them many years of happiness and good health as they look back on a wonderfully productive life that has been given so largely to the promotion of the welfare and happiness of others.

The Committee also wishes to express its gratitude to Dr. Geo. D. Thornton for the untiring assistance he has given during the past few years in connection with many angles of the editorial work including prepublication reading of manuscrips, checking galley and page proof, arranging reprint orders for authors, the mailing of the proceedings and many others.

In all of our expressions of appreciation for the goodwill and helpfulness received from others we would be remiss indeed if we did not on this particular occasion give a deep bow to Mr. Paul Johnston and his wonderfully cooperative staff at the E. O. Painter Printing Company in DeLand for the many times each year they go far beyond what might be termed "the call of duty in printing" by helping in ways that are not only pleasantly surprising but surprisingly effective in producing and distributing the fine volume they have made of the Society's Proceedings during the past few years.



ROGER WILLIAM BLEDSOE

DEDICATION

ROGER WILLIAM BLEDSOE

The staff of the Florida Agricultural Experiment Station and its many friends throughout the State were greatly shocked and deeply grieved by the sudden death of Dr. Bledsoe at his home on January 24, 1960 in the prime of his devoted service to Agricultural Science which he loved so much and served so well.

Dr. Bledsoe was born at Pickens, West Virginia on January 18, 1908. He attended elementary school at Webster Springs where he later served as Principal, 1931-33. This was during the period spent at the University of West Virginia 1929-30 and 1934-36 where he received his A.B. degree. Later he accepted a position as Teaching Assistant at the University of Iowa, 1937-41, during which time he worked for and received the M.S. and Ph.D. degrees.

From 1941 to 1943 Dr. Bledsoe worked as Research Specialist at Rutgers University in which capicity he maintained cooperative contact with E. R. Squibb and Sons and the Allied Chemical and Dye Corporation. In 1943 he came to the Florida Agricultural Experiment Station as Associate Agronomist and served until 1945 when he accepted a position in the Agronomy Department at Cornell University. In 1947 Dr. Bledsoe returned to a full professorship in Agronomy at the Florida Agricultural Experiment Station in which position he continued until June 1, 1954 when he was appointed Assistant Director. Later, on July 1, 1955 he was made Associate Director of the Experiment Station which position he was occupying at the time of his death.

Dr. Bledsoe was a member of Sigma Xi, Gamma Sigma Delta, Gamma Alpha, Iowa Academy of Science, American Chemical Society, American Society of Plant Physiologists, American Institute of Biological Sciences and of the Soil and Crop Science Society of Florida.

The Executive Committee of the Society deems it a very real privilege and honor to dedicate this 20th volume of its Proceedings to the memory of one who devoted his entire life so conscientiously to the advancement of Agricultural Science, himself a long time and always constructive member on its rolls.

HONORARY LIFETIME MEMBERS

1950

Dr. Frederick James Alway
Dr. David J. Hissink (2)
Dr. Walter P. Kelley
Dr. Charles F. Kettering (4)
Charles E. Millar (3)
Dr. Merritt F. Miller
Sir Edward John Russell
Dr. Oswald Schreiner
Dr. Selman A. Waksman
Dr. S. N. Winogradsky (1)

Dr. John G. Dupuis M.D.—Our Country Doctor (1955)

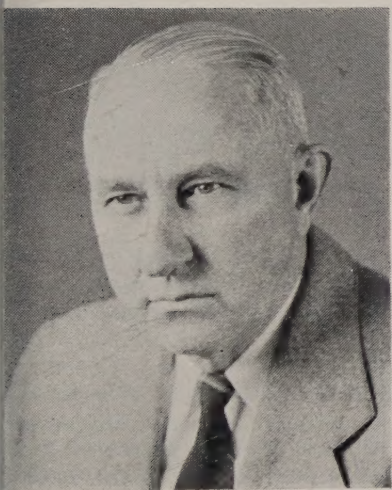
Successors:

(1) Dr. Lyman J. Briggs (1954)
(2) Dr. Harold H. Hume (1956)
(3) Dr. Firman E. Bear (1956)
(4) Dr. Wilson Popenoe (1959)

1960

Dr. Pettis Holmes Senn
Dr. Knowles A. Ryerson
Dr. James E. McMurtrey, Jr.
Dr. H. K. Hayes
Mr. Harold Gray Clayton
Dr. T. Ray Stanton
Dr. G. Steiner
Dr. Emil Truog
Dr. John William Turrentine
Dr. George Dewey Scarseth

NEW HONORARY LIFETIME MEMBERS 1960



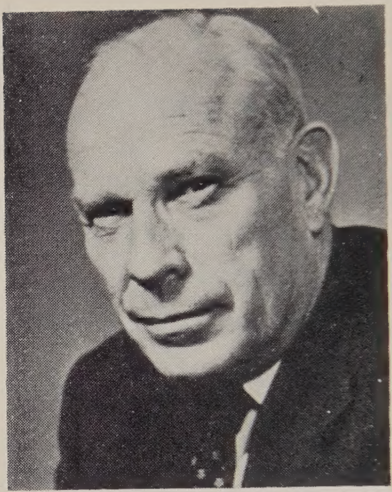
PETTIS HOLMES SENN

(Florida)
Plant Genetics

Pettis Holmes Senn was born October 31, 1890 in Silverstreet, South Carolina. With an undergraduate degree from Clemson College, he enrolled at the University of Wisconsin where he earned the Master of Science and Doctor of Philosophy degrees in the field of Genetics.

Doctor Senn has served as County Agricultural Agent and Plant Breeder with the South Carolina Agricultural Extension Service, as Graduate Assistant and Purnell Corn Breeder at Wisconsin, and as Microscopist at the Kentucky Agricultural Experiment Station. In 1929, he joined the University of Florida Staff as Assistant Professor of Field Crops and Genetics and was promoted to Professor and Head, Department of Agronomy in the College of Agriculture in 1939.

Dr. Senn became Head Professor of Agronomy Emeritus on June 30, 1961 after rendering thirty-two years of faithful and dedicated service to the state of Florida. His congenial personality and genuine interest in his fellow man have created for him hundreds of devoted friends among his former students and faculty associates.



KNOWLES A. RYERSON

(California)
Horticulture

Knowles A. Ryerson was born in Seattle in 1892 and received the B.S. degree in 1916 and the M.S. in 1923, both from the University of California. He was with the Corps of Engineers, U. S. Army in France in 1917-1919 and assisted the U. S. Peace Commission with Agricultural Drainage Investigation in 1919.

Dr. Ryerson was engaged in Agricultural Extension work in California from 1919 to 1925 and served as Horticulturist in Haiti from 1925 to 1928. During this period he also served as Horticulturist to the Joint Palestine Survey Commission in 1927. His connection with the USDA began in 1928 when he was in charge of the Division of Foreign Plant Introduction until 1934 when he became chief of the Bureau of Plant Industry. From 1935 to 1937 he was head of the Division of Tropical and Subtropical Agriculture.

Upon leaving the USDA Ryerson became Professor of Horticulture and Assistant Director of the Experiment Station in charge of the Davis Campus of the University of California until 1952 when he was made Dean of the College of Agriculture, Berkeley, in which position he continued until retirement July 1, 1960.

Dean Ryerson has published many practical and scientific papers dealing particularly with subtropical fruit and has been the recipient of many honors and awards in recognition of his meritorious public service. However, his principal efforts have been administrative. These include among many others: Special Representative, Board of Economic Warfare, Pacific Ocean Area, World War II; Member Research Council S. Pacific Commission 1949-52, U. S. Commissioner 1953-54 and Sr. Commissioner 1954 to date. He has also been Chairman of the Pacific Science Board, Natural Resource Council from 1950 to the present time and was a member of the Administration Board of the Interamerican Institute for Agricultural Sciences, Turrialba, Costa Rica, thru the period of its establishment 1945-52 and its Chairman from 1948-52. Among the many other activities which were constantly claiming his time Dean Ryerson also headed the U. S. delegation to the 7th, 8th and 9th Pacific Congresses in New Zealand (1949), Manila (1953) and Bangkok (1957).

JAMES E. MC MURTREY, JR.

(Maryland)
Plant Physiology

James E. McMurtrey, Jr., was born at Burkesville, Kentucky, in 1893. He received the B.S.A. degree from the University of Kentucky in 1917 and the Ph.D. in 1931 from the University of Maryland where he majored in plant physiology and minored in plant pathology.

Dr. McMurtrey worked his way through the grades in USDA beginning in 1914 from Field Assistant to Senior Physiologist in Tobacco Investigations, Bureau of Plant Industry, and in 1945 was made Principal Physiologist in charge of tobacco investigations in the newly organized Division of Tobacco, Medicinal and Special Crops with the same Bureau. He is currently in charge of Tobacco Investigations in the Crops Research Division of the Agricultural Research Service. In 1956 Dr. McMurtrey was honored with an award for 40 years of service in the U. S. Department of Agriculture.

Dr. McMurtrey is the author or joint author of some fifty scientific publications, primarily in the field of plant nutrition with particular application to tobacco production and fertilization. His scientific ability is internationally recognized for his contribution to the well-known volume "Hunger Signs in Crops," in which he is the author of the chapter on tobacco. He is also the author of "Visual Symptoms of Malnutrition in Plants" published in the book on "Diagnostic Techniques for Soils and Crops."

Dr. McMurtrey has made numerous important contributions to plant and soil science, especially in the field of mineral nutrition. His most outstanding contribution, working with others in this field, was the discovery of the essential role of magnesium for the light soils of the Coastal Plain areas. He also was the first to show boron deficiency for growth of tobacco in typical tobacco soils of the United States. He is the author of the first comprehensive key to nutritional deficiency symptoms in plants.

Dr. McMurtrey's honors and affiliations include membership in Alpha Zeta, Phi Kappa Phi, Sigma Xi, American Society of Plant Physiologist, American Society of Agronomy of which he is a Fellow, and the American Association for the advancement of Science. He is currently recognized as the most outstanding plant physiologist in this country in the field of tobacco research.

H. K. HAYES

(Minnesota)
Plant Genetics

H. K. Hayes, a native of New England, received his B.S. from Mass. State College in 1908, the M.S. in 1911 and the D.Sc. in 1921 from Harvard and an Hon. D.Sc. from University of Massachusetts in 1948.

After working as a special agent in Tobacco Investigations in USDA and as Assistant Agronomist and Plant Breeder in the Connecticut Agricultural Experiment Station he served as Associate Professor, Professor and since 1952 as Professor Emeritus at the University of Minnesota.

Through his research, writings, leadership and teaching he has brought fame to himself and to his university. At the time of his retirement Dr. Hayes was, without question, the world's most outstanding authority in plant breeding. He has been at the forefront of the rapidly growing science of applied genetics during almost the whole of its existence. His research has been a major factor in laying the firm foundation of genetic science on which plant breeding programs are based today. He pioneered in the use of hybridization and pedigree selection as tools for the improvement of self-pollinated plants. He and his associates were the first to transfer valuable genes from one species to another. At that time leading cytogeneticists said it could not be done. Now it is an accepted principle of plant improvement.

Dr. Hayes, as a plant breeder, has had an important place in the team of plant scientists that has given Minnesota farmers a large number of new corn hybrids and various other crops. This team of scientists has set a standard of cooperative scientific endeavor that has become a model for others throughout the world to follow.

Because of his eminence as a scientist Dr. Hayes has been called upon to work in many capacities other than those called for by his duties at the University. In 1941 he served as a member of the Committee to Develop Inter-American Artistic and Intellectual Relations. He was a member of the Board of Collaborators of the U.S. Plant, Soil and Nutrition Laboratory. He has had membership in many scientific societies and served on many committees of those societies. He is a Fellow of the American Society of Agronomy and served as its President in 1935. Following his retirement he became Professor of Plant Breeding, Cornell University Los Banos project and, in this capacity was in charge of the plant breeding research organization of the Philippines. He has been guest lecturer at the University of Florida, North Carolina State College, University of Georgia, University of Kentucky, University of Illinois, Purdue University and Oregon State College.

HAROLD GRAY CLAYTON

(Florida)
Agricultural Extension

Harold Gray Clayton, born near Ocala February 27, 1892, has made an outstanding record while working solely in his native Florida. As administrative or executive officer of the Agricultural Adjustment Administration, established in 1933, which later became the Production and Marketing Administration and is now the Agricultural Conservation and Stabilization program, he was administratively responsible for federal assistance that stimulated the establishment of more than a million acres of improved pastures in Florida. This was a major factor in the almost sensational development of Florida's cattle industry. He was instrumental in securing for Florida and the South many beneficial rulings and developments that have advanced farm living and conservation and improvement of soil resources.

His entire adult career has been spent in outstanding public service to Florida agriculture. He became county agent of Manatee County, Florida, on March 26, 1917. Later that year he joined the United States Army for more than a year of service during World War I. He returned to Manatee County in February, 1919.

On October 4, 1919, Mr. Clayton was named district agent with the Agricultural Extension Service. When the Agricultural Adjustment Administration was created early in 1933, he was drafted to become the first Florida administrative officer, while retaining a cooperative appointment with the Agricultural Extension Service. He was quick to recognize the good that Florida farmers could derive from the AAA program and urged them to take advantage of the assistance it offered.

During World War II he was chairman of the State War Board and rendered yoeman service in arranging for agricultural supplies and in stimulating farm people to extraordinary efford in war crop production, in buying war bonds, in salvage drives, and in other activities connected with the war effort.

On July 1, 1947, he was made director of the Florida Agricultural Extension Service, from which he retired May 31, 1956. The Extension Service made notable advancement under his leadership.

While director of Extension, Mr. Clayton was also administrator of the State Soil Conservation Board and made major contributions to the highly successful soil conservation program in Florida.

He has received numerous honors, including being named Man of the Year in Service to Florida Agriculture by The Progressive Farmer magazine.

T. RAY STANTON

(Maryland)
Agronomy

T. Ray Stanton was born on a farm near Grantsville, Md., September 1885. He was educated in Maryland schools and received the B.S.A. in 1915 and the M.S. in 1921 from the University of Maryland.

After serving as Assistant Agronomist at the Maryland Agricultural Experiment Station he was appointed Scientific Assistant and placed in charge of small-grain investigations at the once famous Arlington Farm in Virginia. 1921 he was put in charge of the Oat Investigations project in which capacity he continued as its active head, advancing through the classified grades as Associate Agronomist, Agronomist and Senior Agronomist until retiring as the age of 66 years in 1951.

During this long and brilliant scientific career Dr. Stanton and his co-workers were instrumental in the breeding and development of many improved, disease-resistant varieties of oats, which placed the oat crop of the United States on a much better economic status. He directly contributed to the development of more than 55 oat varieties that have been named and distributed throughout he country.

Dr. Stanton is the author or joint author of some 160 publications including USDA bulletins, circulars and special articles in various scientific and agricultural journals. Among these, the two most notable were "Superior Germ Plasm in Oats," and "Oat Identification and Classification." This latter bulletin is rated as the most complete and inclusive of its kind ever published in any country.

During his long career he was a member of various scientific societies including the American Society of Agronomy, the American Genetic Association, the American Association for the Advancement of Science, the Phytopathological Society of America, the Agricultural History Society, and the Washington Botanical Society. He was elected a "Fellow in the American Society of Agronomy" in 1943 for directing and conducting outstanding research in oat improvement.

On June 15, 1945 the honorary degree of Doctor of Agriculture was conferred on him by the Iowa State College of Agriculture and Mechanical Arts for his achievements in the field of Plant Science, especially for the breeding of superior disease-resistant oats.

G. STEINER

(Puerto Rico)
Nematology

Gotthold Steiner was born in Signau, Switzerland in 1886 and received his M.S. and Ph.D. degrees from the University of Bern in 1908 and 1910, respectively. After a short stay in Italy he returned to Bern in 1913 where he continued as Privatdozent until 1918. He came to the United States in 1921 as Seessel Research Fellow at Yale University, intending to return to Switzerland a year later. He decided to remain in this country instead and became affiliated with the USDA—a relationship that lasted until 1956 when he retired as Head Nematologist of the Section of Nematology, Horticultural Crops Research Branch, to accept the position of Nematologist with the Department of Entomology, Agricultural Experiment Station, University of Puerto Rico at Rio Piedras.

Among the many important contributions Dr. Steiner has made to the literature of his chosen field, the one that stands out to many workers and especially to the members of our Society is the remarkably fine paper he presented before the 4th annual meeting of the Society which was published in Proceedings Volume IV-B under the title "Plant Nematodes the Grower Should Know." Coming at that particular time and quickly receiving world-wide distribution, it is known to have had a very decisive effect on the development of the Science of Nematology as from that date.

During his tenure in the Department of Agriculture, Dr. Steiner was most diligent in his efforts at working with growers, training personnel, and contributing new knowledge of nematodes. In consequence of his prolonged and thorough efforts his contributions have been considerable to the science which at last has come to be recognized for its almost fearful importance to the successful growing of plants which are susceptible to numerous pathogenic nematodes that infest soil in all parts of the world.

Dr. Steiner is a member of many national and international societies and the recipient of numerous honors during his exemplary career of service to science. His research interests in nematology are comparative anatomy and parasitology.

EMIL TRUOG

(Wisconsin)
Soil Science

Emil Truog was born March 6, 1884 on a farm near Independence, Wisconsin. He received his education in the schools of Wisconsin including the M.S. degree from the University of Wisconsin in 1912.

From 1909 to the present Truog has served the University of Wisconsin as Instructor, Assistant and Associate Professor, Professor and, since his retirement in 1954, as Professor Emeritus. To implement his research work Truog gathered around himself eager young students to learn with him. Over the years students came to work with him from over the world and returned to serve as ambassadors for the scientific study of soil each in his own country. Today the University of Wisconsin leads all the states in total number of graduate students in soils. This has been due in large degree to Truog's influence on the stature of the Soils Department in Madison.

Beginning about 1915, Truog strongly upheld the view that mineral soil acidity is due to alumino-silicic acids rather than to the much proclaimed adsorption phenomenon. His thesis was subsequently substantiated. Also, largely through his efforts, the practice of using starter fertilizer for many crops and the use of soil tests for determining fertilizer needs have gained universal adoption.

Professor Truog has always been greatly concerned with promoting interest in soil science at the international level. He has attended many of the International Soil Science Congresses throughout the world, and served effectively on committees for the Congress. He served as General Manager of the Seventh International Congress of Soil Science which was held at the University of Wisconsin in 1960. During recent years interest in Soil Science has greatly increased everywhere as leaders like Truog have come to recognize the close relationship of food production and health to the promotion of world peace.

Professor Truog is a Fellow in the American Society of Agronomy and the American Association for the Advancement of Science; Honorary member of International Society of Soil Science and Soil Conservation Society of America; Member of the American Chemical Society; in 1938 served as President American Society of Agronomy; in 1954 as President of the Soil Science Society of America. He has received many citations from different organizations, among them one from the Soil Conservation Society of America which especially sums up Professor Truog's life and work—for "Outstanding Contributions through Teaching, Research, and Leadership in the science of the wise use of soil and water resources."

JOHN WILLIAM TURRENTINE

(Washington, D. C.)
Agricultural Chemistry

John W. Turrentine received his Ph.D. and M.S. degrees by 1902 from the University of North Carolina and his Ph.D. from Cornell in 1908, after which he joined the chemistry staff of Wesleyan University in Connecticut. In 1911 he became research chemist to investigate known potash raw materials for USDA. In this capacity he helped meet the nation's emergency need for potash when the German supply of this vital mineral was cut off by World War I. He accepted the presidency of the American Potash Institute in 1935 and developed the Institute into a scientifically-dedicated team of regional directors and agronomists whose sole purpose is to cooperate closely with official agriculture in "finding the proper scientific place for potash in American agriculture."

It is a matter of record that most people call Dr. John W. Turrentine "the father of the American potash industry."

Out of Dr. Turrentine's many contributions to American agriculture and the potash industry, perhaps the most historic one was the invention of a process for vacuum cooling and crystallizing potash salts. This invention revolutionized the potash industry which had previously used vat cooling and crystallizing methods. At the same time he designed, constructed and operated a plant for extracting potash from kelp.

Throughout his career Dr. Turrentine remained constantly abreast of current conditions and advances within the scientific work by actively participating in many national and international societies and associations. He is a member of the American Chemical Society, American Institute of Chemical Engineers, American Association for the Advancement of Science, American Society of Agronomy, Soil Science Society of America and many others international in scope. In 1937 the Academie D'Agriculture de France awarded him its gold medal for his work with potash.

Dr. Turrentine is author of several books and scientific publications on potash. His whole creed—and the creed of the Institute he helped to form—is wrapped up in a comment he made to the first meeting of the Institute's Directors—"potash use depends on the recognition of its function as a plant food, which is agronomic, the ability of the farmer to buy his requirement, which is economic . . . . we believe that the prosperity of the consumer is the best assurance of the prosperity of the producer." The potash industry accepted his philosophy and through its Institute has completed 25 years of applying scientific integrity to the wheels of commercial enterprise under his inspiring leadership.

GEORGE DEWEY SCARSETH

(Indiana)
Agronomy

George D. Scarseth, Soil Scientist and Agronomist, is Director of Research for the American Farm Research Association. Formerly he was Professor of Agronomy and head of the Agronomy Department at Purdue University. He has served at different times as Soil Scientist on the teaching and research staffs of the College of Agriculture in Alabama, Connecticut and Wisconsin. Dr. Scarseth started his scientific career in 1926 as Soil Chemist in Central America for the United Fruit Company. Later he was Agricultural Research Consultant on tropical soils for Standard Fruit and Steamship Company and in recent years has served as Agronomic Consultant to the University of Alaska. Since 1957 he has been Consulting Agronomist for Central Farmers Fertilizer Co.

He graduated from the University of Wisconsin in 1924 and most of his graduate work at Yale was done in Geology and Chemistry. As a DuPont Fellow he obtained his Ph.D. degree in soil science and plant physiology at Ohio State University in 1932.

Dr. Scarseth is a Fellow in the American Society of Agronomy and American Association for the Advancement of Science and a member of several honorary and scientific societies. He received "Freedoms Foundation Awards" in 1951 and 1952. In 1952 Purdue University conferred on him the honorary degree of Doctor of Science. He was a delegate to the 5th International Congress of Soil Science, Belgian Congo, 1954.

Dr. Scarseth has published many scientific papers and books. His more popular articles number well over one hundred. These deal chiefly with the problems of obtaining more efficient production from the land on a permanent basis with "built-in" conservation. Much earthy science and philosophy is mixed into these as well as into the numerous lectures he makes and especially in a book which he has just finished entitled "Everybody Loves the Land."

His research in soil fertility, especially as related to growing corn as a soil building and conservation crop, has been referred to as revolutionary, and has brought into general farm practice many sound innovations in the growing of this important crop. He is listed in Who's Who in America, American Men of Science and World Biography. Dr. Scarseth owns a private demonstration farm near his home in LaFayette, Indiana, where he tests in a completely practical manner new principles as they are developed before they are recommended for public use.

The High Road in Crop Production

GEORGE D. SCARSETH*

About a year ago Mrs. Scarseth and I took the "High Road" in Scotland from Edinburgh through the Trossachs to Sir Walter Scott's lakes and dells of Lake Lomond. We returned on the "Low Road" through farms and meadows.

Both areas are rich. One is rich in culture, which tourists buy, and the other is rich in goods to sell from its fields and factories.

Florida, too, has both the high road in its climate to sell to tourists, and its low road from which to sell its productions of the land and industries.

Florida has about 58,000 square miles of land and water with about 69 people per square mile. Holland has about 859 people per square mile (1955), much of which is land made from the bottom of the sea.

If Florida were to use its land as intensively, and be as thickly populated as Holland, there would be about 50 million people to house and feed.

"It can't happen here," says the skeptic. "Perhaps Florida has not been discovered yet," says the optimist. I say, "Florida will receive more and more people each year from otside as population expands and people discover what can be done through research for new ways in this amazing State."

Let us scan the horizon of the future with respect to some factors that may be in the making that may affect Florida.

Florida's sand is an asset. In this new scientific age heavy soils are a handicap from implement compaction, poor drainage, excessive runoff and deficient aeration. Sands are highly adaptable to scientific management.

Florida's gentle to flat topography is an asset. I have come to look at good topography, where machines can be readily used, as one of the most valuable features of land.

Your low, poorly drained swamps would be no obstacle to the Dutch. Eventually the Everglades will be gone, but there is still the sandy bottom to use for planting around the margins where the underlying rock is covered with such a Florida mantle to varying depths. When the need justifies these can be used, and in fact, are being used in some areas where a few years ago there was a covering of from one to several feet of organic matter. Your rainfall is your greatest resource. The whole nation dreads to face up to its impending water shortage. With 40 to 100 inches of annual rainfall, you have but to find ways to control its runoff, and to ride through the dry gaps. This has only an economic obstacle since the water in available.

California's people are thinking of going to Washington State (Columbia River) for water. Florida's people need never go to Washington (D.C.) for this important commodity. More than likely they will go to Washington, D. C. for some of Washington's (federal) money to use in developing Florida, and invite the retired people living in California to come and live in a land where water falls out of the sky.

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*Director of Research, American Farm Research Association, West Lafayette, Indiana.

Your temperatures and your sunshine (between the showers and an occasional big blow) make Florida a mecca for living.

From the crop production standpoint, the mildness of the Florida winters is a double asset. Some one will say, "You haven't experienced a killing frost yet with a small fortune tied up in a winter crop." To this my reply must be, "Russia, lying mostly north of latitude 50 is heavy in a research program moving forward in crops adapted to cold and is expecting to win all races in food production with the temperate and subtropical world." My own experiences in Alaska, while limited, convince me that coldness of the soil, or frost in the air, while not tolerated by tender crops, is no serious handicap to growing many plant species.

The coldness of the soil was a handicap in grandfather's day, because no organic matter decayed in a cold soil. Plants thus starved for nutrients that were released only in a warm soil.

It is not news to a Southern planter that nitrates start plants off fast in cold soils, but this is a fact which is still largely overlooked both North and South of the Dixie Line.

We have not exhausted the possibilities of feeding some nutrients through the leaves for a few weeks while the soils are still too cold.

When I see the experiments at Athens, Georgia where Coastal Bermuda Grass is in a rotation with corn, and how this once disgraceful "weed" which was a pest before research, is now about to open a whole new way for cattle production, I feel a bit worried about the livestock competition facing the old Corn Belt.

The Coastal Bermuda grass is a new product from research. When this grass is supplied with 600 to 800 pounds of nitrogen per acre on irrigated and mineral fertilized soil, it produces 7 to 8 tons of hay, which in dried pellets appears to be equal to the expensive, but highly favored pelleted alfalfa for poultry and cattle producers.

On top of all these virtues, this Bermuda appears to reduce the amount of nematodes in the soil that hurt corn so that after about 4 years of this Coastal Bermuda the soil is again ready for a big corn yield.

But the corn plant itself is in its own revolution of changes in production and uses. It appears that favorite hybrid varieties are under fire, where leading farmers are trying to "shoot for the moon" for high corn yields.

In 1960 in Indiana, at least ten farmers had whole fields in a contest to try to make a yield of 300 bushels per acre. So far none have made it, but I heard a farmer or two express disappointment that they made only about 200 bushels per acre. They considered this a failure! With this new type of farmer-crowding-research-people, a big task is staked out for us.

In the Corn Belt research is in progress (W. M. Beeson—Purdue University) showing that the whole corn plant may be fed to animals. The grain or ears will go with the stalks while green, and made into dried pellets, or into moist silage. This would make the grain or ear corn obsolete. The poor pig would have to move out of the Corn Belt where ear corn or corn liquor could still compete.

Well, this won't happen over night—the ear corn belt or pig belt might move into other areas.

I have looked with satisfaction on the vast development in Florida toward timber and pulpwood production. This is certainly timely for our current status, but the question is raised, "Can we afford to use all this good topography, rainfall, and growing temperatures for cellulose produc-

tion?" Will the current land use tie up land for a more valuable general development of other resources needed for a lot more people in the future? This is a far-reaching issue beyond the scope of this discussion.

Your research programs impress me with their forward look and quality. I like to think there is strength in your diversified efforts at various Experiment Stations over the State.

It is obvious that research should not be too streamlined by bureaucratic organization. In such a system there is a danger of becoming involved in a "way of doing" and thinking, sort of beating a popular drum together as it were. It's too close for comfort to what we think of as "brainwashing."

Research should be team work, but brain work only in individuals, so I've become somewhat allergic to "planned thinking," so popular in committees these days.

This Soil and Crop Science Society of Florida is one of the healthiest instruments I've encountered to get team work without brainwashing. I have been your admiring member from the start, therefore, was greatly honored to be invited to speak at your meeting.

CONTRIBUTED PAPERS (CROPS)

Gordon B. Killinger, Presiding

A Three-Year Study of Drying High Moisture Snapped Corn With Heated Air[1]

DALTON S. HARRISON and VICTOR E. GREEN, JR.[2]

Cotton and Ashby (2) have summarized the main reason for properly drying and storing field corn and small grains. They stated that 5% of the world production of cereal grain is destroyed by insects. They also stated that corn in the deep south may be destroyed at the rate of 9% per month. They pointed out that grain in low moisture is unfavorable to insect development and recommended that moisture content not exceed 11% for most grains.

There are a number of reasons why corn should be planted early in the spring and harvested as early in the summer as conditions permit in south Florida. In addition, the corn should be promptly dried and stored following harvest. Varieties grown in the area are very tall and their leaves remain green longer than corn belt varieties. Corn is made at 35% moisture and can be pulled any time after the kernels reach that point. The best yields of corn have resulted from February plantings. A prompt harvest precludes excessive growth of weeds between lay-by and harvest. Stalk break and root lodging increase with maturity. Early harvest also releases land for a succeeding sorghum crop for grain or silage prior to cold weather. The longer corn remains in the field, the longer it is subjected to damage by bobolinks, grackles and redwing blackbirds. Damage by rats, mice and raccoons progresses after silking. Corn is nearly always damaged by field infestation of "stored grain" insects in Florida. The rainy summer season and the prevalence of certain fungi lead to cob rots resulting in ears with soft cobs that are subject to disintegration in the mechanical picker. In wet weather, grain on cobs can sprout, on both standing and broken stalks. Fields become boggy during late summer due to heavy rains.

It would be a rare exception for kernel moisture to diminish enough for safe cribbing of corn in south Florida. Therefore, some method of artificial drying should be used.

Since tight cribs must be used, air must be supplied through mechanical means. Unheated air in the Belle Glade area has a relative humidity of 100% nearly every night in the year from about 6 p.m. to 9 a.m. It is not uncommon for RH of air during the day to remain nearly at 100%. Hygrothermograph records at the Everglades Experiment Station show that the RH of the air can remain at 100% for a four-day period (96 hours). It

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The authors wish to acknowledge the assistance of Mr. Dallas Nehls, Maintenance Supervisor at the Everglades Experiment Station, who operated the dryer and determined kernel moistures, and Mr. H. M. Spelman, III, for the photographs. Appreciation is due the McConnell Sales and Engineering Corp., Birmingham, Alabama, Mr. Roy M. Blanton, Agent, for the heating system, motor and controls.

should be evident that unheated air is unsuitable in that area to reduce moisture content of corn. Therefore, heated air seems to be the only practical method for drying corn in south Florida.

This study is concerned with the factors involved in the use of liquified petroleum gas as a source of fuel to heat air for drying corn.

METHOD OF PROCEDURE

Experiments on drying high moisture snapped corn with heated air have been conducted for the past three years (1957-59) at the Everglades Experiment Station, Belle Glade, Florida (4). The field corn was harvested with a moisture content ranging from 21 to 30% and placed in three bins 8′ high x 14′ in diameter for immediate drying. The three bins are in line and receive the heated air from ducts leading in from the rear.

The dryer is a type RR-57 Agricultural Heater; 5 h.p., 3-p. motor and direct Partlow temperature control; 500,000 B.T.U.; 10,000 C.F.M. @ 1½″ S.P. The dryer (Figure 1) is set directly behind the center of number 2 bin and is directly connected to a main duct 36.5 feet long x 4 feet wide x 2 feet deep. Three separate ducts from the main duct connect to the rear of each corn bin. Individual control gates are installed in each of the 3 ducts leading to each corn bin in order that simultaneous or individual drying of each bin may be accomplished; that is, when the first bin is filled after harvesting, the gates to number 2 and 3 bins may be closed so as to direct all the heated air into bin number 1. As soon as number 2 bin is filled, the gates to it may be opened and drying begun. With this arrangement each bin has an air flow of 21.6 CFM bu. USDA recommendations are 8 to 10 CFM bu. for ear corn with 25% moisture or 1,000 CFM per sq. ft. for the main duct (1). Each bin has a floor space of 154 sq. ft. and a total capacity of 1232 cu. ft. or 500 volume bushels of corn; however, on a shelled corn basis each bin will hold 268 bushels of grain.

As soon as the drying operation was commenced, the temperature control was set at 140 F.. Moisture checks were made every 6 hours in each bin at 2, 4, and 6 foot depths of snapped corn and the average moisture content is reported in Table 1.

RESULTS

Results of three years of drying are tabulated in Tables 1 to 3. In the summer of 1957 there were 690 bushels of shelled corn dried as snapped corn. The initial moisture content averaged 22.6% and the final moisture content was 14.3% (Table 1). Total moisture removed (3) was 6,500 pounds of water or 10 pounds per bushel (Table 3). The cost of electricity and fuel was slightly in excess of 15 cents per bushel (Table 2). Total number of hours the dryer was in operation was 138. Consumption of LP Gas was 3.8 gallons per hour.

In 1958, there were 804 bushels dried as each bin was filled at a cost of 23 cents per bushel. The initial moisture content was 25% while the final was 14.8%. Total water removed was 9,675 pounds or 12 pounds per bushel. The dryer was in use a total of 211 hours at a gas-use rate of 4.48 gallons per hour. (Table 2).

During the last season of the experiment, (1959) 804 bushels were dried simultaneously at a cost of almost 18 cents per bushel (Table 2). The

TABLE 1.—KERNEL MOISTURE CONTENT OF SNAPPED CORN USED IN DRYING EXPERIMENTS AT BELLE GLADE, FLORIDA (1957-59)

Year	Corn	Opr. Time	Moisture Content: Before Drying Range	Before Drying Avg.	After Drying Range	After Drying Avg.
	bu.	hrs.	%	%	%	%
1957	690	138	21.3-24.2	22.6	12.8-15.8	14.3
1958	804	211	23.5-26.2	25.0	14.7-15.0	14.8
1959	804	193	29.6-31.7	30.4	14.1-14.9	14.6

average initial moisture content was 30.4% and was brought down to 14.6%—a removal of some 15,825 pounds of water or 18 pounds per bushel. The dryer was in operation only 193 hours for the same volume as dried in 1958. Also, the 1959 corn had a higher moisture content. Gas-use rate was 4.07 gallons per hour. This gives rise to the point that the unit is more efficient when drying all 3 bins simultaneously than singly.

SUMMARY

Results of 3 years data on drying high moisture corn in multiple bins with LP Gas have shown that total costs of electricity and fuel average 3.5 and 15 cents per bushel, respectively, when the moisture is reduced from 26.0 to 14.5%. When considered on a volume bushel basis, the cost is about 11 cents per bushel for electricity and fuel. The efficiency of the

TABLE 2.—COSTS OF ELECTRICITY AND LP GAS FOR DRYING SNAPPED CORN IN SIMULTANEOUS BINS. BELLE GLADE, FLORIDA (1957-59).

Year	Corn	LP Gas Used	Elec.	Cost/Bu.* LPG**	Cost/Bu. Elec.***	Total
	bu.	gal.	KWH			
1957	690	525	649	$0.121	$0.033	$0.154
1958	804	945	992	$0.187	$0.043	$0.230
1959	804	737	691	$0.146	$0.030	$0.176
Avg.	----	-	----	$0.151	$0.036	$0.185

*Cost/Bu. Based on Shelled Corn.
**LP Gas at $0.16/Gal.
***Elec. at $0.035/KWH.

TABLE 3.—WATER REMOVED BY DRYING SNAPPED CORN, BELLE GLADE, FLORIDA (1957-59).

Year	Corn Dried	Opr. Time	Kernel Moisture Initial	Kernel Moisture Final	Water Removed/bu.	Appx. total Water Removed
	bu.	hrs.	%	%	lbs.	lbs.
1957	690	138	22.6	14.3	10.0	6,500
1958	804	211	25.0	14.8	12.9	9,675
1959	804	193	30.4	14.6	21.1	15,825

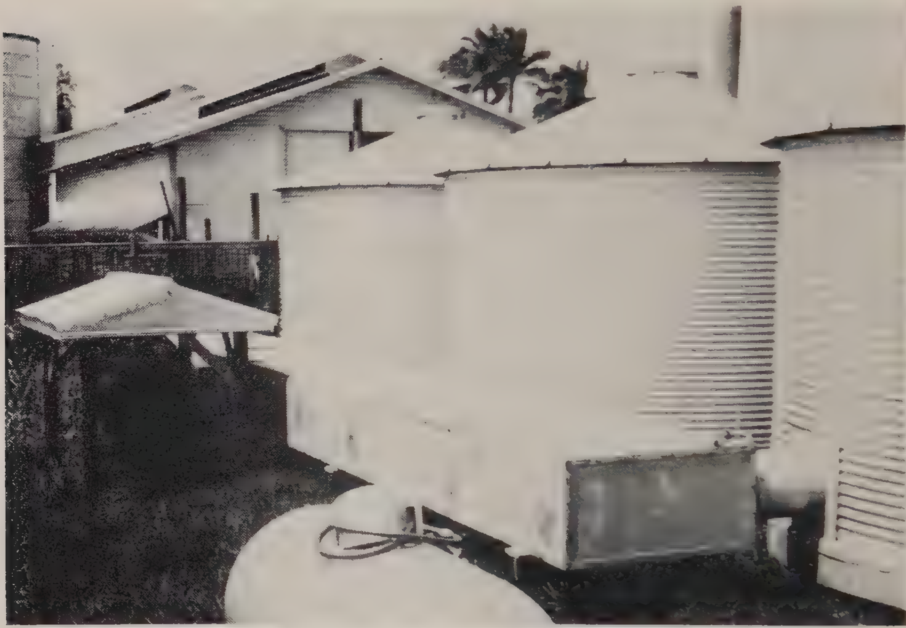

Fig. 1.—Rear view showing arrangement of dryer, ducts and corn bins.

3-bin system is greater when all bins are in operation simultaneously, rather than drying each bin individually. The overall efficiency of the unit is reflected in the drying years of 1958 and 1959. In 1958 a bin was filled and the dryer turned on. There were a number of hours before the second bin was filled and turned on; consequently, the rate of air flow was

$$\frac{10,000}{268} = 37$$ cubic feet per minute per bushel. At this rate of air flow, the air did not stay in the bin long enough to pick up its full load of moisture and as a result the fuel consumption was high. Whereas, in 1959, the harvest proceeded rapidly and it was only a few hours until all three bins were operating simultaneously. As a result the rate of air flow was decreased to 12 CFM/bu. The best fuel economy was obtained during the year 1959.

The small capacity dryer used with the 3-bin system lends itself to farm adaptation where bins are already installed and eliminates moving the dryer to individual bins. Cattlemen might likewise use such an installation when growing corn for feeding operations.

LITERATURE CITED

1. Anonymous. Drying Ear Corn with Heated Air. USDA Leaflet No. 333. 1952.
2. Cotton, R. T. and Wallace Ashby. Insect Pests of Stored Grain and Seed. In: Yearbook of Agriculture 1952, Insects. USDA, pp. 629-639. 1952.
3. Gowder, M. T. and D. P. Schwab. Storing and Drying Corn and Grain on the Farm. Agricultural Extension Service, University of Tennessee Publication 325 (Revised). 1952.
4. Harrison, D. S. and V. E. Green, Jr. Drying Corn with LP Gas. Agricultural Leaders Digest, 39 (8); 14. September 1958.

Fertility, As A Limiting Factor For Pastures In Florida[1]

O. CHARLES RUELKE[2]

INTRODUCTION

Productive pastures do not develop naturally on Florida land after the trees and underbrush has been removed as they do in some places in the world. On the contrary, productive pastures must be planned, built, and maintained. One of the factors which seriously limits the establishment and maintenance of productive pastures in Florida is soil fertility.

LITERATURE REVIEW

Early work of Blaser, *et al.* (1) has conclusively demonstrated the need for the proper amounts of the right fertilizer at the time of establishment of improved pastures. Today, it is common knowledge that improved pastures grown in Florida must have additional fertilizer or they will be replaced by the native vegetation.

Since these facts have been recognized, numerous researchers have carried out experiments to determine specifically which of the essential elements were critical for pastures and how deficiencies could be corrected.

Many workers have shown that the response from the application of nitrogen to grasses was striking. In Florida, Blue *et al.* (2) obtained yields of 5,420, 7,200, and 9,900 pounds of dry matter when they applied 96, 192 and 288 pounds of nitrogen per acre respectively to pangolagrass.

Wallace *et al.* (5) reported significant increases in growth of pangolagrass fertilized with nitrogen up to 240 pounds per acre, but reported no significant increased response when nitrogen rate was raised to 480 pounds per acre. Racine[3] obtained significant increases in yield of pangolagrass and Coastal bermudagrass when nitrogen was applied at rates up to 540 pounds per acre. Lysimeter studies of Volk (4) reported that yields of pangolagrass increased from 5.8 to 7.6 tons of dry matter per acre and yields of Pensacola bahiagrass increased from 4.2 to 7.6 tons per acre when nitrogen rates were increased from 240 to 480 pounds per acre. Creel[4] found serious winter killing in pangolagrass fertilized at rates higher than 224 pounds per acre of nitrogen.

Using the specific conductivity test of cold hardiness, Dunavin *et al.* (3) showed that pangolagrass plants fertilized with 400 pounds of nitrogen per acre rated far less cold hardy during the winter than where 100 pounds were used.

The following study has been carried out to determine how soil fer-

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[3]Racine, R. G. The Responses of Pangolagrass and Coastal Bermudagrass to High Nitrogen Fertilization. Unpublished Master's Thesis, University of Florida. 1955.

[4]Creel, J. M., Jr. The Effect of Continuous High Nitrogen Fertilization on Coastal Bermudagrass and Pangolagrass. Unpublished Master's Thesis, University of Florida. 1957.

tility and other factors affected the total yields, forage distribution, and winter survival of pastures in Florida.

MATERIALS AND METHODS

Plots of Coastal and Suwannee bermudagrass, Pensacola and Argentine bahiagrass and pangolagrass were established on Arredondo loamy fine sand on the Agronomy Farm at Gainesville, Florida. Management treatments consisted of continuous grazing, as simulated by repeated cutting treatments, and reserved grazing, where no forage was removed in the fall or winter. Fertility treatments consisted of the application of the equivalent of 500 pounds per acre of 6-6-6 fertilizer applied annually in early spring. Three additional applications of nitrogen fertilizer were made to reach the 100, 200 and 400 pound per acre per year levels. These additional applications of nitrogen were made in May, July and September except for the early fertilized pangolagrass which received the additional nitrogen in May, June, and July. A split plot experimental design was used.

The experimental plots were harvested with a mower and the forage yields were determined on an oven dry basis. Forage yields, forage distribution, and winter injury were ascertained.

RESULTS

Results of four years of work are shown in Table 1. These data show little difference between the productive capacity of the various varieties and species of grasses under similar management and fertility treatments during the first season following establishment. Initially Coastal outyielded Suwannee bermudagrass principally because it became established more rapidly but later there was no significant difference. Pensacola outyielded Argentine bahiagrass in the early spring and late fall. The total yearly yields were not significantly different at Gainesville. Yields of pangolagrass which received the late fertilizer treatment were larger than pangolagrass with the early treatment due to the distribution of nitrogen throughout a longer part of the growing season. Yields of pangolagrass during the first growing season were comparable to the yields of bahiagrass and bermudagrass under corresponding treatments. During the later years the yields of pangolagrass were lower due to severe winter injury which occurred in certain treatments.

The total annual yield of forage available from plots which were continuously cut was essentially the same as on those plots which produced reserved forage, during the first year following establishment. However, serious winter injury, occurred in subsequent years in pangolagrass with the greatest injury occurring in plots where grass was reserved.

Nitrogen fertilization had a highly significant effect on the forage yield and distribution of forage throughout the year on all of the grass varieties tested. In general, total annual yield of the grasses was almost doubled when nitrogen was increased from 100 to 400 pounds per acre for the year. The greatest response per pound of nitrogen fertilizer applied occurred when the levels were increased from 100 to 200 pounds per acre per year. Increasing to 400 pounds did not give proportional increases in yield.

TABLE 1.—POUNDS OF OVEN DRY FORAGE CLIPPED PER YEAR FROM DIFFERENT PASTURE SPECIES AND VARIETIES, AND FROM VARIOUS MANAGEMENT AND FERTILITY TREATMENTS(1) AT GAINESVILLE, FLORIDA.

Forage Species and Variety	Mgt. Treat.	Nitrogen Per Year	Dry Matter Yield 1956	Yield 1957	Yield 1958	Yield 1959	4 Year Average
		lbs./A	lbs./A	lbs./A	lbs./A	lbs./A	lbs./A
Coastal		100	8160	7130	6160	6130	6900
Bermudagrass	Cut	200	12120	11930	10230	11170	11360
N. Fert		400	15480	12790	12400	13840	13630
May		100	11070	7640	7450	8520	8670
July	Res.	200	11050	10540	10670	10990	10810
September		400	12160	13350	12150	13680	12840
Suwannee		100	7940	7850	6630	7540	7490
Bermudagrass	Cut	200	10200	9690	10570	11170	10410
N. Fert.		400	11750	9100	13120	15470	12360
May		100	7140	9340	9930	10440	9210
July	Res.	200	11240	8130	11830	13430	11160
September		400	12460	8530	12880	15440	12330
Pangolagrass		100	7390	5960	3200	4830	5350
(Fert. Early)	Cut	200	9380	9400	5700	8670	8290
N. Fert.		400	11000	11440	8190	12680	10830
May		100	6740	6950	3850	7800	6340
June	Res.	200	9150	8850	8100	13380	9870
July		400	11480	10970	8620	11800	10720
Pangolagrass		100	7580	6370	5530	6380	6470
(Fert. Late)	Cut	200	10160	9180	8820	11620	9950
N. Fert.		400	11930	12810	7950	11780	11120
May		100	8090	4890	5810	9660	7110
July	Res.	200	10290	7960	10280	9910	9610
Sept.		400	12600	11880	8180	10490	10790
Argentine		100	6450	4650	5600	4810	5380
Bahiagrass	Cut	200	9980	7480	12050	8570	9520
N. Fert.		400	13100	10520	13800	14130	12890
May		100	6470	5460	7410	6640	6500
July	Res.	200	9240	6060	11960	10230	9370
Sept.		400	13280	11500	15030	14400	13550
Pensacola		100	6200	5980	6350	4780	5830
Bahiagrass	Cut	200	8600	9920	9340	8170	9010
N. Fert.		400	12650	13940	15150	13390	13780
May		100	7180	5460	7050	5570	6320
July	Res.	200	10690	9020	10300	8490	9630
Sept.		400	13670	12370	13370	10300	12430

(1) All plots received the equivalent of 500 pounds of 6-6-6 fertilizer applied annually in early spring. Three additional applications of nitrogen fertilizer were added to reach the three nitrogen levels.

TABLE 2.—POUNDS OF OVEN DRY FORAGE CLIPPED AND PERCENTAGE OF WINTER INJURY OF PANGOLAGRASS WITH VARIOUS MANAGEMENT AND FERTILIZER TREATMENTS(1) AT GAINESVILLE, FLORIDA.

Forage Tested	Mgt. Treat.	Pounds Nitrogen Per Acre Per Year	Total Dry matter 1957	Estimated Winter Injury 4/14/58	1st Cutting Yield 5/25/58	Total Dry matter 1958	Estimated Winter 3/23/59	1st Yield Cutting 5/26/59	Total Dry matter 1959
Pangolagrass		100	5960	27.0	270	3200	5.0	500	4830
Fertilized	Cut	200	9400	65.0	120	5700	5.0	600	8670
Early		400	11440	80.0	70	8190	13.0	740	12680
May		100	6950	47.0	110	3850	2.0	850	7800
June	Res.	200	8850	80.0	580	8100	12.0	730	13380
July		400	10970	73.0	90	8620	76.0	300	11800
Pangolagrass		100	6370	43.0	990	5530	5.0	810	6380
Fertilized	Cut	200	9180	35.0	1460	8820	10.0	1400	11620
Late		400	12810	77.0	140	7950	17.0	740	11780
May		100	4890	13.0	770	5810	7.0	940	9660
July	Res.	200	7960	13.0	1550	10280	24.0	1000	9910
Sept.		400	11880	60.0	620	8180	93.0	180	10490

(1) All plots received the equivalent of 500 pounds of 6-6-6 fertilizer applied annually in early spring. Additional nitrogen was added to reach the three nitrogen levels.

The effect of nitrogen fertilizer on winter injury of pangolagrass was of greatest importance and is shown in Table 2. These data show that increasing the amounts of nitrogen generally increased the amount of winter injury in pangolagrass. Despite this fact, the application of nitrogen up to the rate of 200 pounds per acre per year resulted in more available forage at the first cutting of pangolagrass than where 100 pounds of nitrogen was used. On the other hand, where 400 pounds of nitrogen was used, winter injury was so severe that these plots did not produce as much in the first cutting as did the 100 or 200 pound rates. In the winter injured plots which had received 400 pounds of nitrogen, it took most of the summer to reestablish pangolagrass and therefore the total seasonal yields were often less than in plots which only received 200 pounds of nitrogen. Applying the same rates of nitrogen earlier in the growing season did not seem to result in less injury or faster recovery following frost.

Winter injury occurred also in the bermudagrass and bahiagrass plots which received heavy rates of nitrogen. However, these plants were able to recover rapidly due to the fact that they have regenerative plant tissues which were protected by the soil.

SUMMARY AND CONCLUSIONS

The effect of three rates of nitrogen fertilizer (100, 200 and 400 pounds per acre per year), and two management treatments (continuous grazing, simulated by cutting, and reserved grazing, simulated by leaving a cover of grass going into the winter) were studied on several varieties of bahiagrass, bermudagrass and pangolagrass fertilized both early and late in the season at Gainesville, Florida.

There was little difference between the productive capacity of the various varieties and species of grasses under similar management and fertility treatments in the season following establishment of the grass.

Nitrogen fertilization had a highly significant effect on the forage yields on all of the grasses tested. The effect of nitrogen fertilization on winter injury of pangolagrass was of greatest importance. The 200 pound rate of nitrogen on pangolagrass produced the most forage even though less injury occurred in the 100 pound rate. Plots receiving 400 pounds of nitrogen produced considerably less forage in subsequent years due to severe winter injury. Earlier applications of the same amounts of nitrogen did not reduce winter injury of pangolagrass.

Similar winter injury occurred in bahiagrass and bermudagrass which received high levels of nitrogen. However, these grasses were able to recover without serious reductions in yield. Because pangolagrass responded readily to nitrogen and was sensitive to cold temperatures, it was an excellent indicator grass to use to study fertility, as a limiting factor for pastures in Florida.

LITERATURE CITED

1. Blaser, R. E., W. E. Stokes, J. D. Warner, G. E. Ritchey, and G. B. Killinger. Pastures for Florida. Florida Agr. Exp. Sta. Bul. 409. 18-21. April, 1945.
2. Blue, W. G., and Nathan Gammon, Jr. Rates and ratios of nitrogen, phosphorus, and potassium for white clover and pangolagrass on Rex fine sand. The Soil Sci. Soc. of Fla. Proc. 15:208-218. 1955.
3. Dunavin, L. S., Jr., and O. C. Ruelke. The evaluation of cold hardiness in Florida pasture grasses. Soil and Crops Sci. Soc. of Fla. Proc. 19:172-178. 1959.

4. Volk, G. M. Efficiency of various nitrogen sources for pasture grasses in large lysimeters of Lakeland fine sand. Soil Sci. Soc. of Amer. Proc. 20:41-45. 1956.
5. Wallace, A. T., G. B. Killinger, R. W. Bledsoe, and D. B. Duncan. Effect of nitrogen fertilization on the production of pangolagrass and bahiagrass. Soil Sci. Soc. Proc. 15:198-201. 1955.

Popcorn Quality And The Measurement Of Popping Expansion[1]

VICTOR E. GREEN, JR. and EMMETT D. HARRIS, JR.[2]

Quality in popcorn grain assumes major importance since practically the entire crop is grown for only one reason—popping for human consumption. This is a $460,000,000 annual business in the U.S.A. The most important index of quality in popcorn and upon which most of the other factors are considered is expansion upon popping.

That good yields of high quality popcorn can be grown in Florida was shown by Green and Harris.[3] During an eight year period, 92 varieties were screened. The best varieties were grown in a number of years, representing both good and poor growing seasons. Yields as low as 435 and as high as 5040 pounds per acre of shelled grain were obtained. The overall average of 24 varieties grown between two and six years each was 2228 pounds per acre.

This paper outlines quantitative tests used to ascertain popcorn quality.

FACTORS AFFECTING THE QUALITY OF POPCORN

Quality of popcorn is affected by many factors beginning with the planting of the crop and continuing after the corn leaves the popper.

Before Harvest—

The size of individual grains is affected by anything that affects plant growth, the more common of which are drought, inundation, insects and premature drying due to leaf diseases. Stunted plants usually yield stunted ears. Infestation by insect larvae causes many grains to fail to pop.

The moisture content of the grain when harvested in very important. Bemis (7), Eldredge and Thomas (9), Huelsen and Bemis (10) and Richardson (12) have stressed this point. The ability of corn kernels to pop increases as the grain is dryed down to between 35 and 25 percent. However, at such high moisture, great care must be taken not to scar or crack the

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Gratitude is expressed to the Ames Seed Farms, Ames, Iowa and the Central Popcorn Company, Shaller, Iowa for furnishing seed for these tests and for determining ear corn quality, weight per bushel, and expansion ratios. Special thanks are due Mr. Forrest Wanberg, Mr. Charles D. Fist and Mr. James R. Murray of those companies, without whose help these tests could not have been conducted. Some of the statistical procedures were performed by Mr. Ronald L. Jones, who also photographed the drawings made by Edward King, Jr.

[3]Green, Victor E., Jr. and Emmett D. Harris, Jr. Popcorn Tests, Everglades Area 1952-1959. Everglades Station Mimeo Report 60-5. September 1959.

soft grains at this stage by picker-shellers, or mechanical corn pickers. Cribbing corn at that moisture content is impossible in Florida. Corn should not be shelled above 20 percent and not above 15 percent moisture is preferable. The ears should not be left on the stalks any longer than necessary. In Florida, it would probably be best to mechanically harvest popcorn at about 20 percent moisture and dry the ears artificially to not less than 13 percent.

Hull thickness is least at 29 to 27 percent moisture, but, again, a little quality is best sacrificed while moisture content is permitted to drop before harvest.

After Harvest—

Corn pops best if it is dried naturally, but it is often advantageous to apply artificial heat. Less quality is lost if the corn is dried on the ear. Huelson and Bemis (10) reviewed the literature on drying popcorn artificially and concluded that a maximum of 110° F. was the best temperature.

After harvest and drying, popcorn must be protected from insects and rodents. Any trace of the presence of rodents in a lot of popcorn may render it subject to condemnation proceedings. Insect damage is unsightly and detrimental to popping.

The temperature and relative humidity of storage facilities should be so maintained that there is no appreciable change in moisture content. From a practical standpoint, it is easier to control moisture in ear corn than shelled corn. Also, it is easier to reduce moisture than to increase moisture in popcorn. For this reason, care must be taken to prevent drying below 13 percent, by weight, since corn pops best between 13 and 14 percent moisture.

Popcorn can be stored for long periods of time. Dexter (8) recommended that the relative humidity of the storage facility be about 75 percent, or that the corn be sealed in moisture-proof containers. He could not locate any sample of popcorn, regardless of age, that could not be restored to good popping quality, provided it had not been injured in the initial drying.

The weight per bushel, a reflection of the specific gravity, of popcorn has a bearing on the size of individual popped grains, but does not appreciably affect popping volume since the change to the weight-volume method of testing outlined below. However, a high weight per bushel value denotes that the individual grains are plump and well filled with expansible starch. In 1954 at Belle Glade, expansion of the kernels was reduced by 2.5 to 8 volumes by Helminthosporium leaf blight, which caused dry leaves on the plants when the grain was in the milk stage.[3]

In the Popper—

Regardless of the care exerted by the grower and the processor, unless certain conditions are met in the popping basket, pan or machine, poor quality popped corn will be the result.

The criterion that affects quality is the potential expansibility of the kernels.

Hull thickness varies with maturity and variety grown. The ideal variety would, of course, have no hull and idealists have named certain varieties alluding to that dream, such as Japanese Hulless. The next best goal would be to have a variety that would shed its hull completely immediately after popping.

The industry refers to the oil in which corn is popped as "seasoning," a genuine misnomer since the ideal seasoning is devoid of flavor or odor. Brunson and Richardson (6) stated that commercial seasonings usually have a coconut-oil base and contain artificial coloring. The usual proportion is 10 to 20 percent as much seasoning as unpopped corn, depending on personal preferences. Eldredge and Thomas (9) generally recommended that seasoning be used at the rate of about 30 percent by volume of the unpopped corn. In 1959, Koffman and Eldredge found that the greatest popping volume was obtained when seasoning was used at 50 percent of the volume of raw corn.[4] It is important that the corn be at normal room temperature so that it will not appreciably decrease the temperature of the oil. Corn kept under refrigeration should be allowed to reach room temperature before popping. The corn should start to pop in from 60 to 90 seconds to give best results (6). Bemis (7) wrote that a cup of properly conditioned corn would begin to pop in about 85 seconds and finish popping in another 60 seconds.

Tenderness is dependent largely on popping expansion and the shape of the popped kernel. The popped corn should be kept dry, or if additives are used for coating the kernels, they should be added to dry, popped corn.

Shape of the raw and popped kernels is a function of the variety and moisture content of the raw corn. Weaver and Thompson (15) found that ears with pointed kernels yielded 1.69 volumes average higher than those with rounded kernels. The shape of the popped kernel is described by flake shapes: "mushroom, intermediate and butterfly." The mushroom type is preferred for sugarcoating or where the popped corn is handled or transported before it is sold. The roundness of the flake prevents breakage in handling which would reduce the volume and flake size. The butterfly type gives higher expansion ratios and is more commonly seen.

In the absence of gravimetric ovens and electric meters, qualitative measures can be used to ascertain whether corn is too dry or too wet (less than 13 or more than 14 percent moisture by weight) to give large, smooth flakes. Bemis (7) suggested that if corn pops slowly and not very large, with considerable steam coming from the popper, it is probably too wet. If it pops with a weak sound, and is still small, it is probably too dry. Brunson and Richardson (6) stated that popcorn that is too dry pops with a smooth fracture, as contrasted with a slightly roughened surface at the correct moisture content and a rough surface when too moist.

Commercial popcorn grain is either white or yellow. Blue, red, brown, purple and probably other colors, also exist. These colors are in the aleurone and or pericarp. Endosperm colors are yellow or white, only. Therefore, popped corn will be white only from white varieties and light yellow from yellow varieties. At Belle Glade, observational poppings of corn with dark aleurone colors revealed kernels that were whiter than those popped from white popcorn. Any other colors in popped corn must be added after popping.

POPPING EXPANSION

All factors listed above affect the popping quality or expansion. Therefore, the expansion figure is the critical measurement.

[4] Koffman, Alex J. and John C. Eldredge. Popcorn experiments for 1959. Iowa Agr. Exp. Sta. Mimeo.

Since there are no data to the contrary, it is assumed that American Indians discovered that certain kernels would pop when they were parching corn to eat. Now it is known that the high content of hard starch in popcorn along with the steam generated by heat causes the kernels to evert better than grains of other types of corn, sorghum, millet or other grains. In 1957, an unselected variety from Panama expanded only 10 volumes.[3] Selection and hybridization have caused remarkable improvement in popability. In 1937, Bronson (5) reviewed popcorn breeding to that date. His example to explain popping volume showed a 24:1 ratio. His figure 2 shows that individual ears popped between 16 and 35 volumes, and about 90 percent of the ears averaged 20 and 29 volumes. He stated that in Kansas, expansions had been increased from 19:1 to 26:1 in 6 years, that little increase had been effected since that time, which indicated to him (in 1937) that the practical limit of improvement had about been reached. The average popping expansions of 81 hybrids in Kansas in 1935 was 24.1:1. The highest figure was 28.5:1.

Weaver and Thompson (15) traced improvement in Illinois. Between 1940 and 1952, expansion was raised from 21.7 to 37.8.

In the 1958 Yearbook of Agriculture, Bronson had raised his sights. He and Richardson (6) stated that there were no standard grades for popcorn. They suggested a system of premiums for high expansion similar to those paid for high-protein wheat. They also suggested the following grades:

Expansion	*Grade*
Less than 25	Poor
25 to 30	Fair
30 to 35	Good
More than 35	Excellent

The data shown below were derived from Everglades Station Mimeo Report 60-5 plus the 1960 crop data. From 4 to 23 varieties per year were planted between January 28 to March 6, with an average planting date of February 11. Three-foot rows were used with plant populations of 14,520. Four replications in randomized complete blocks were employed. Insects were controlled as necessary. The corn was harvested when mature. After being dried at 110 F. until a safe moisture was reached, samples of 10 ears were selected at random from each variety and sent to the cooperating popcorn company. There, ear corn quality was determined, the samples were shelled, equalized to 13.5% moisture and popped. The official volume test was used every year, and both that test and the weight volume test were used in 1958-1960.

Figure 1 traces the improvement in popping quality of the varieties grown at Belle Glade between 1953 and 1960 using the official volume test. As early as 1955, expansion ratios of 40:1 were obtained. In 1954 and 1957, northern leaf blight assumed epiphytotic proportions. The effect of premature drying of the leaves is reflected in the lower expansion figures. A gradual upward trend is indicated. In 1960, expansion figures averaged 40 volumes for 19 varieties, with a low of 37.1 and a high of 43.3.

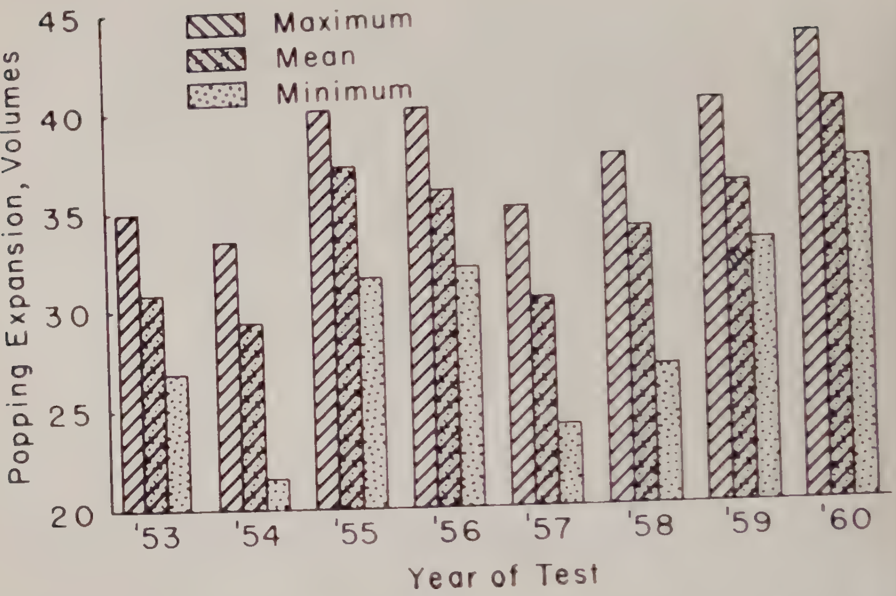

Fig. 1.—Maximum, mean and minimum popping expansion ratios of varieties of popcorn at Belle Glade, 1953-1960. Note decreased expansions in 1954 and 1957 due to pre-mature drying of leaves by northern leaf blight.

QUANTITATIVE TESTS FOR POPPING EXPANSION

The Official Volume Test (OVT)

This test was adopted in 1946 (1) and used officially until 1956. The principle involved was to compare the ratio of a given volume of popped corn to a unit of the same measure of raw corn from which it was popped. This was the first step toward standardizing quality by the industry. The machine used in this test is shown in Figure 2.

The disadvantage of this method was that it did not take into account the weight per bushel of the corn. Since popcorn is sold by weight, the processors desired to know the expansion ratio by weight.

Huelson and Thompson (11) found that by using the measuring cup provided with the standard machine recommended by the National Association of Popcorn Manufacturers weight deviations were as high as 7 grams, which would induce an error of between 3 and 5%, depending upon the total weight of corn in the cup.

Although they offer no solution for this uneven filling, it would seem that the problem could be overcome as it has in taking a weight per bushel test.

The Weight Volume Test (WVT)

The weight volume tester was approved for use by the Popcorn Processors Association on October 1, 1956 (2). The WVT is a measure of expansion expressed as cubic inches of popped corn per pound of raw popcorn. A charge of 150 grams was established (3, 4) apparently on the

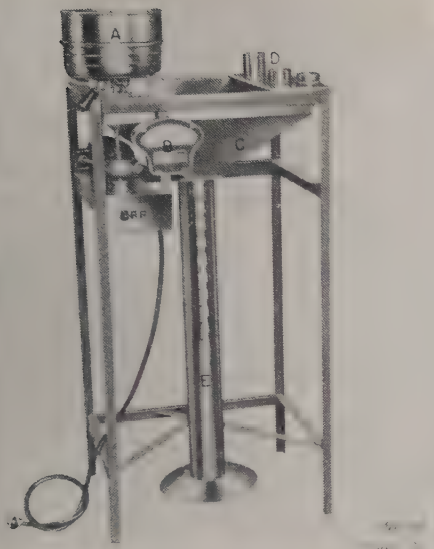

Fig. 2.—The Cretors official volume tester used from 1946-1956. A-popping element with agitator, B-continuous reading pyrometer, C-hopper, D-volume cups and oil measure, E-measuring tube calibrated from 15 to 33.

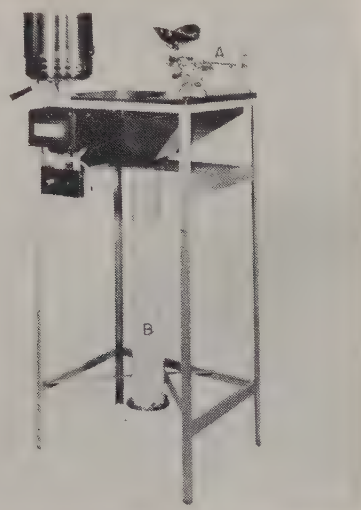

Fig. 3.—The new Cretors weight volume tester used since 1956. A-gram scale to replace the volume cups, B-plastic tube to replace metal tube, calibrated from 700-1200 cu. in. per lb. of raw popcorn.

assumption that 3 times 150 grams equal one pound. But one pound equals 453.6 grams, and 453.6 divided by 150 equals 3.024 (10). The tube is graduated from 700 to 1200 cubic inches per pound of raw popcorn as shown in Figure 3. This method is a weight to volume test while the OVT is a volume to volume test.

Comparison of the OVT and WVT—

Using the old method of testing, a grower of light, chaffy popcorn had almost an equal chance with the grower of plump, heavy popcorn since an equal volume of the two samples of the corn was compared.

The group that is put into the most advantageous position by the new test is the purchaser of processed raw popcorn, that is, the movie houses, concession stand operators, etc., since they buy popcorn by weight and sell it by volume. It seems to the writers that such a case is unprecedented wherein the consumer is given an advantage over the processor, by the processor himself.

One of the objects of this study was to compare the two methods of testing and to establish the validity of the new method.

In 1958, 1959 and 1960 both the OVT and the WVT were performed at Ames, Iowa on representative samples of the varieties grown at Belle Glade. Co-variance analyses indicated highly significant positive correlations between the two tests. See Figures 4, 5, and 6.

The WVT was plotted against the OVT for each variety of popcorn. There were 18 varieties in 1958 (Fig. 4); 23 in 1959 (Fig. 5); and 19 in 1960 (Fig. 6). The regression formulae were calculated and are shown.

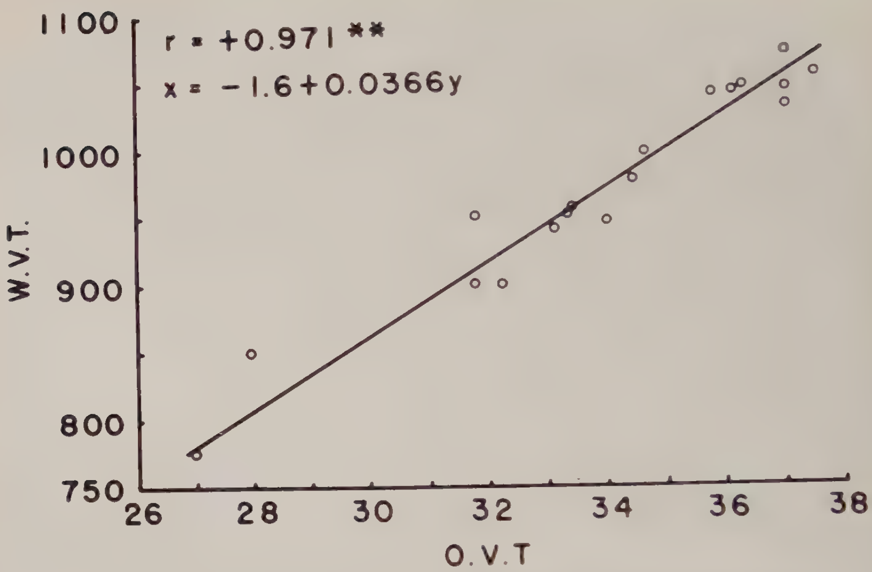

Fig. 4.—The relation of OVT to WVT for 18 varieties at Belle Glade. 1958.

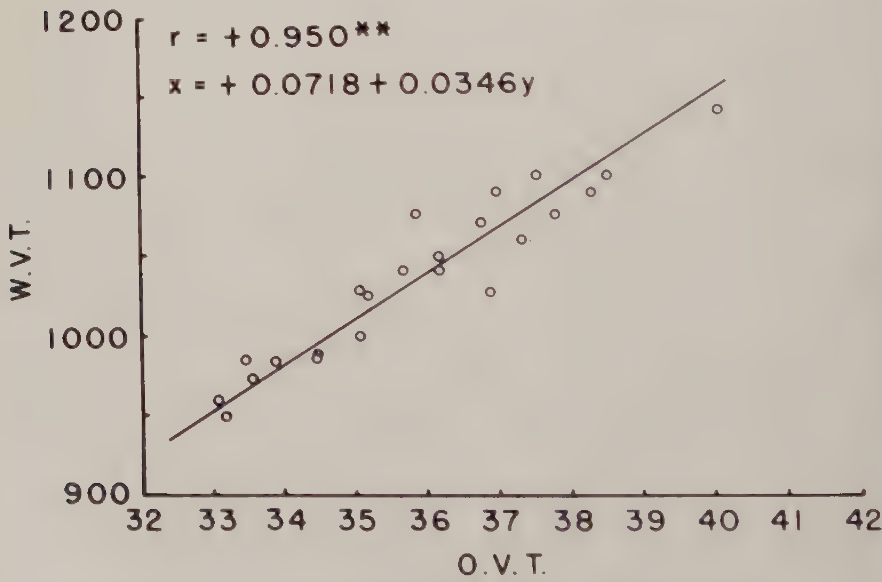

Fig. 5.—The relation of OVT to WVT for 23 varieties at Belle Glade. 1959.

along with the best fitting lines drawn therefrom. Similar data from Iowa by Eldredge and Thomas (9) and Thomas and Eldredge[5] utilizing essentially the same varieties grown in Iowa were subjected to the same

[5]Thomas, W. I. and John C. Eldredge. Popcorn Experiments for 1957. Iowa Agr. Exp. Sta. Un-numbered publication. 3 text pages, 6 tables.

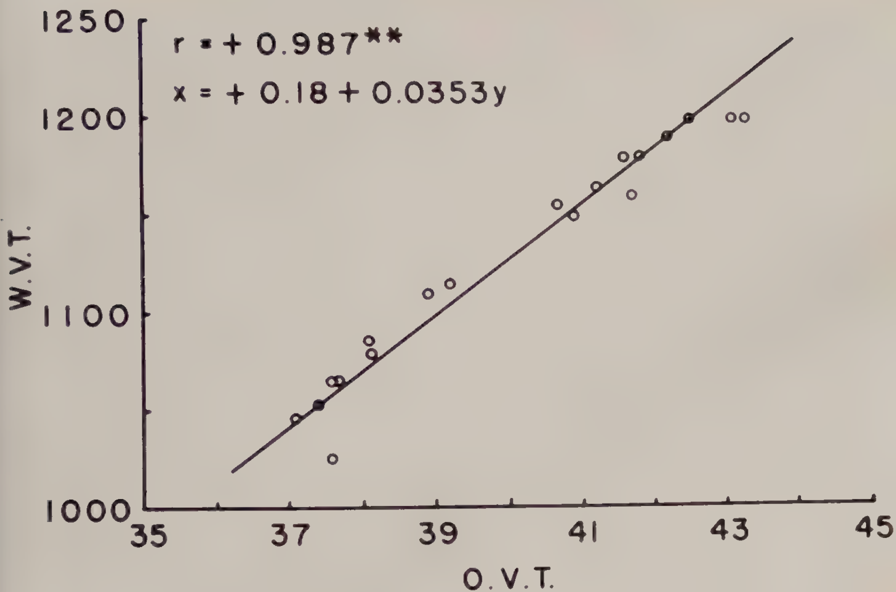

Fig. 6.—The relation of OVT to WVT for 19 varieties at Belle Glade. 1960.

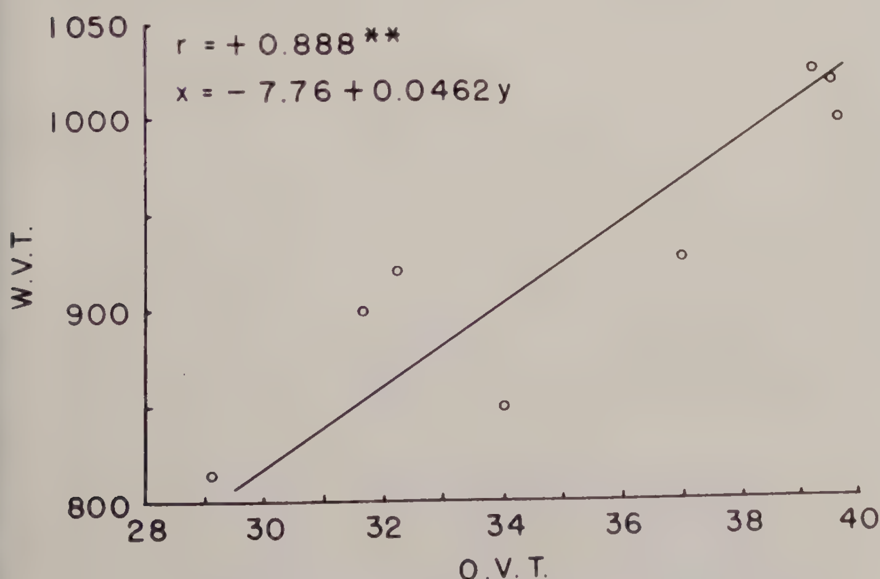

Fig. 7.—The relation of OVT to WVT for 8 varieties at Ames, Iowa. 1955-1957.

statistical analyses, but only the data from Eldredge and Thomas (9) were plotted. See Figure 7.

The combined data at Belle Glade for 1958, 1959 and 1960 appear in Figure 8.

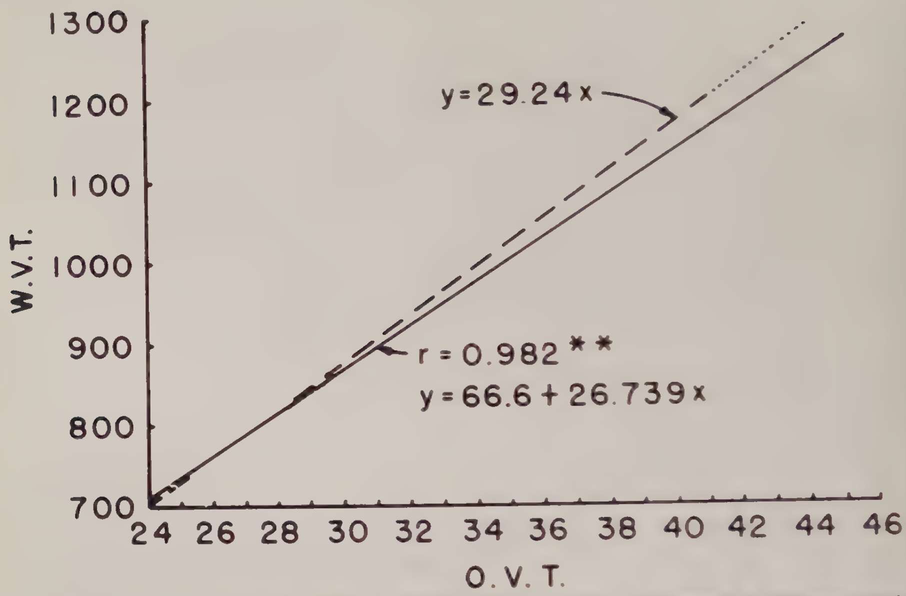

Fig. 8.—A chart to convert OVT to WVT. The conversion suggested by Huelsen and Bemis (10) gives higher WVT values than those calculated from data at Belle Glade. See also Table 1.

The data show that there is very close agreement between the two testing methods as evidenced by the highly significant correlations in all except one case wherein the "r" value was significant only at the 5% level. These data prove conclusively that the new method of testing is valid and that the processing industry was fortunate to have such a sound method to adopt as the weight volume test. However, as shown by the data in Figure 6, the popping expansion at Belle Glade was beyond the limit of 1200 cu. inches per pound making necessary an adaptation in the tube in the very near future.

According to the manufacturers of popcorn testing machines, it is not advisable to use conversion charts to compare the new and the old methods of determining popping expansion. It has already been pointed out that errors of 3 to 5% would be induced easily with the OVT (11). Huelsen and Thompson also worked out a conversion factor that is apparently valid. They stated that correspondence with commercial processors indicated that the trade desired a conversion table. They proceeded as follows: In 6 years of experimental work all the popping samples were weighed after measuring. The weights ranged from 175 to 200 grams, with an average of 195 grams for all types of popcorn. Thus, the ratio between the old and the new systems was 0.7692 (150 divided by 195). One volume in the original metal tube 4 inches in diameter is 12.57 cu. inches. Therefore 12.57 times 0.7692 equals 9.669 cu. inches in the new plastic tube. To convert to the calibration in the new tube (cu. inches per pound raw popcorn): 453.6 grams per pound divided by 150 grams sample equals 3.024; and 9.669 x 3.024 equals *29.24*, the factor for converting one volume of popped corn with the old system to cu. inches per pound in the new system.

In Figure 8 a chart was made from the tabular data presented by Huelson and Bemis and extended by extrapolation to 44 volumes after multiplying 29.24 times 42, 43, and 44 volumes as shown above. The line drawn from data of Huelson and Bemis is the more optimistic since they calculated higher expansion figures for cu. inches per pound from expansion ratios than were obtained in three years at Belle Glade. This is due to the fact that their conversion scale was predicated upon the average weight of volume samples of 195 grams that ranged from 175 to 200 over a six-year period in calculating the factor of 29.24, while the line representing the relation of OVT to WVT at Belle Glade was calculated from actual samples run by both methods of testing over a three year period on samples that were equalized to 13.5 percent moisture before popping. The regression line was calculated in terms of "x" and individual popping volumes were then calculated from the regression equation. Table 1 shows the comparison of the data obtained by Huelsen and Bemis and by the present authors.

TABLE 1.—A COMPARISON OF CALCULATED CONVERSION FACTORS FOR DETERMINING CUBIC INCHES PER POUND OF RAW POPCORN (WVT) WHEN USING KNOWN EXPANSION RATIOS (OVT).

OVT Volumes, X:1	Weight Volume Test Cu. In. Per Pound Illinois[1]	Florida[2]	OVT Volumes X:1	Weight Volume Test Cu. In. Per Pound Illinois[1]	Florida[2]
24	702	708	37	1082	1056
25	731	735	38	1111	1083
26	760	762[3]	39	1140	1109
27	790	789	40	1170	1136
28	819	815	41	1199[3]	1163
29	848	842	42	1228	1190[3]
30	877	869	43	1257	1216
31	906	896	44	1287	1243
32	936	922	45	1316	1270
33	965	949	46	1345	1297
34	994	976	47	1374	1323
35	1023	1003	48	1404	1350
36	1053	1029	49	1433	1377

[1]Based on 6 years data. Calculated from weighed volume samples.
[2]Based on 3 years data. OVT and WVT run on sub-samples of the same sample after reconstitution of moisture to 13.5%.
[3]Volumes for OVT over 41 in Illinois and below 27 or above 42 in Fla. are extrapolations.

Economic Gain from Increased Expansion.—

In 1952, Eldredge stated that for each point increase in expansion, there was a greater return of $4.50 per 100 pound bag of raw popcorn at the popper. He cited the examples from calculating the volume of the sacks used by three vendors and estimating the number of sacks that would be filled from corn of differing qualities. A 100 pound bag of 26-volume corn brought $115, 30-volume corn $133, and 34-volume corn $154.

Spiegel (14) stated that the minimum net profit from a popcorn machine should be $100 per 100 pound bag of raw popcorn. This can be extended by more efficient operations and better corn to almost $140 profit per 100 pound bag.

Figure 9 shows the relation of the expansability of popcorn to expected returns from corn of varying qualities. In the example shown, each increase of 100 cu. inches per pound per 100-pound bag of raw corn permits the filling of 142 additional 70 cu. inch (2" x 5" x 7") boxes, which if sold at 10 cents each, would bring in an additional $14.20. This example is within reason when viewed in relation to a recent statement by Spiegel (13) to the effect that in 1956 and 1957, the better machine operators were popping 1500 10-cent boxes per 100 pound sack of raw corn and that one operator reported that he was getting 1800 to 1900 boxes in 1960.

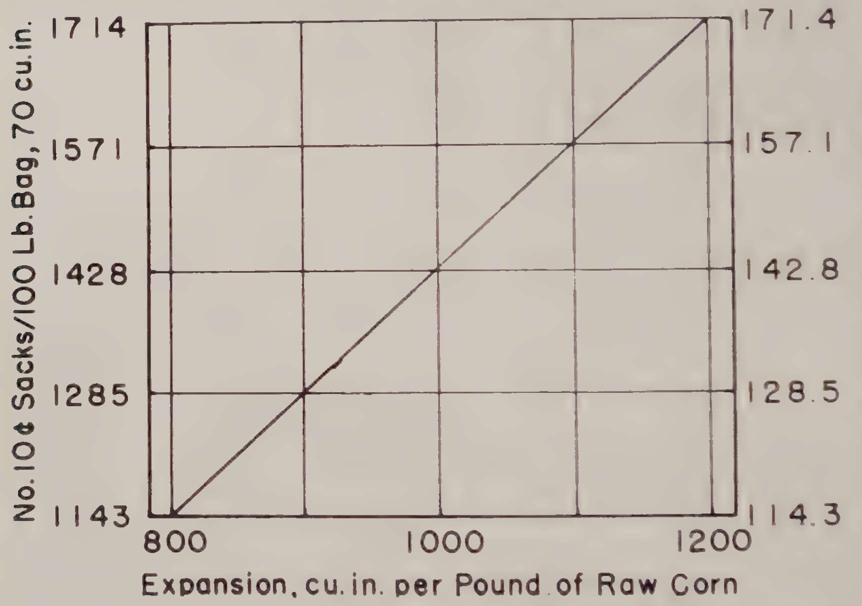

Fig. 9.—The relation of expansability of popcorn to expected returns from corn of different qualities. Each increase of 100 cu. in. per lb. per 100 lb. bag gives 142 more 10¢ sacks of popped corn.

Insect Damage—

From 1956 through 1959, popcorn from variety trials was examined for damage by caterpillars and stored grain insects. In evaluating each type of damage, individual ears from 10 to 25-ear samples per plot were given scores from 0 to 5, indicating the degree of damage from none to most severe, respectively. Each score was multiplied by the number of ears receiving that score, the sums of products taken and divided by the total number of ears in the sample. This quotient was multiplied by 100. Thus each replicate of each variety received a score between 0 and 500 to indicate the degree of damage suffered from each type of insect.

Most of the damage to popcorn by caterpillars in the Everglades has been caused from caterpillars feeding from the tip of the ear downward. Although most of the literature describes the corn earworm, *Heliothis zea* (Boddie) as entering the ear through the silk channel with the damage beginning at the tip and the fall armyworm, *Laphygma frugiperda* (J. E.

Smith), as chewing through the husk and beginning its damage at the side of the ear, observations on sweet corn have indicated that, in the Everglades, both species commonly enter the ear through the silk channel and that damage to the side of the ear rarely occurs. As the corn had been husked and caterpillars long since departed at the time of examination, the species of caterpillar which had attacked popcorn ears could not be determined.

The scores used for evaluating earworm damage to the tip of the ear are shown in Table 2. Damage to the sides of the ears was never great enough to be used in comparing varieties although a scoring system based on the number of damaged kernels was set up as follows: 0) no damage; 1) 1-4; 2) 5-9; 3) 10-14; 4) 15-19; 5) 20 or more kernels.

TABLE 2.—METHODS USED IN SCORING POPCORN EARS FOR DAMAGE BEGINNING AT THE TIP OF THE EAR BY CATERPILLARS.

	Depth of Damage Below Ear Tip		
Score	1956	1957	1958 and 1959
0	none	none	none
1	to ⅛ length of ear	to tip	to ⅛ length of ear
2	¼	to ½ inch	to ¼
3	1/3	1¼ inch	⅜
4	½	2½ inch	½
5	½ plus	2½ inch plus	½ plus

Although earworm damage scores in one year, 1957, were based on linear distance that damage extended from the tip it is felt that a system based on the proportion of the length of the ear to which the damage extends is better in the type of trials conducted at the Everglades Experiment Station. Such a system seems to more accurately reflect the effect of the insect damage on yield of popable corn, especially where varieties differ greatly in the size of ear produced. If one were selecting lines for use in a breeding program to establish insect resistant varieties, a score based on linear distance of damage extension from the tip of the ear might be a better value.

The earlier method for evaluating damage by stored grain insects was based on the number of damaged kernels on each ear of the sample as follows: 0 no damage; 1) 1-10; 2) 11-20; 3) 21-30; 4) 31-40; 5) 41 or more damaged kernels. Plot scores were calculated as for caterpillar damage. This method was too laborious and time consuming and thus limited the number of ears from each plot that could be examined. In later years, the sample was first shelled and 100 kernels taken and examined for the number damaged by stored grain insects. The stored grain insect usually encountered has been the rice weevil *Sitophilus oryza* (L.). A damaged kernel is recognized by a small round hole through which the adult has emerged.

SUMMARY AND CONCLUSIONS

1. Popcorn is a $460,000,000 annual business in the U.S.A.
2. Good yields of high quality popcorn have been grown in experimental plots at Belle Glade. The average yields of 24 varieties grown between two and six years each was 2228 pounds per acre of shelled corn.

3. Popcorn quality is affected by many factors: all of those that affect field corn plus some factors peculiar to itself. Popcorn is used exclusively for human food, more commonly as a confection. For this reason, great care is exercised to maintain high quality and good sanitary measures.

4. More care must be given in harvesting, drying and handling popcorn than field corn to prevent cracking the pericarp.

5. The most important factors affecting popcorn quality are expansion, taste and tenderness.

6. Since 1935 average expansion ratios have been raised from 20 to 43 volumes through selection and hybridization. Company advertising, standard grades and methods of testing quality have barely remained abreast of the improvement in the crop.

7. The official volume test (OVT) was used from 1946-1956, and was an expression of the number of volumes of popped corn per unit volume of raw corn. Being a volume to volume test, it was subject to errors in sampling. Since popcorn is sold by weight, the industry desired a test that used a weight to volume measurement.

8. The weight volume test (WVT) has been used since 1956 and is an expression of the cubic inches of popped corn per pound of raw corn. Differences in weight per bushel are accounted for in this test, and samples of equal weight are used.

9. The validity of the new test is sound as evidenced by the data presented herein. Almost perfect positive correlations were obtained from data derived from both tests on identical samples.

10. Conversion factors, using tables and charts, while not recommended by manufactures of the testing machine, are valid. The scheme advanced in Illinois, while slightly higher than that in Florida, seems to be valid. Consumers would be guaranteed a higher expansion figure with the Illinois system.

11. The new method of testing allows the vendor to view popcorn quality on an economic basis. He can quickly calculate his expected income from a machine if he knows the volume in cubic inches of the boxes or sacks that he fills with popped corn.

12. Criteria for quantitatively ascertaining the damage to quality in popcorn varieties due to caterpillars and stored grain insects are outlined.

LITERATURE CITED

1. Anonymous. New Popcorn Volume Tester. The Popcorn Merchandiser 1 (6): 11-13. 1946.
2. —————. Popcorn Processors Association Debut Revised Weight-Volume Tester. The Popcorn and Concessions Merchandiser 11 (7): 21-22. 1956.
3. —————. Popcorn Processors Adopt New Official Weight Expansion Tester for Industry. Ibid. 12 (1): 8. 1957.
4. —————. Cretors Designs New Official Weight-Volume Testers for Popcorn Industry. Ibid. 12 (5): 24. 1957.
5. Brunson, Arthur M. Popcorn Breeding. In U.S.D.A. Yearbook of Agriculture. 1937. pp. 395-404. 1937.
6. ————— and Dewayne L. Richardson. Popcorn. U.S.D.A. Farmers Bulletin 1679. 1958.
7. Bemis, W. P. Popcorn—Harvesting and Conditioning for Maximum Popping. Illinois Research, Winter 1959:10-11. 1959.
8. Dexter, S. T. Conditioning Popcorn to the Proper Moisture Content for Best Popping. Michigan Agr. Exp. Sta. Quar. Bul. 29: 64-69. 1946.
9. Eldredge, J. C. and W. I. Thomas. Popcorn—Its Production, Processing and Utilization. Iowa Agr. Exp. Sta. Bul. P. 127. 1959.

10. Huelsen, W. A. and W. P. Bemis. Changes in Popcorn Kernels and Cobs While Maturing. Ill. Agr. Exp. Sta. Bul. 625. 1958.
11. ______________ and A. E. Thompson. Artificial Drying of Popcorn in Relation to Popping Expansion. Amer. Soc. Hort. Sci., Proc. 60. 341-350. 1952.
12. Richardson, D. L. Pericarp Thickness in Popcorn. Agro. Jour. 52: 77-80. 1960.
13. Spiegel, Syd. Why Do People Buy Popcorn? Concessionaire Merchandiser 15 (1): 4, 6, 7, 18. 1960.
14. ______________. Popcorn Machine is Key to Greater Profits. Ibid. 15 (4): 16-17. 1960.
15. Weaver, B. L. and A. E. Thompson. White Hulless Popcorn: Fifteen Generations of Selection for Improved Popping Expansion. Illinois Agr. Exp. Sta. Bul. 616. 1957.

Problems In Grain Sorghum Production In West Florida[1]

M. C. LUTRICK[2]

Sorghums are grown for grain quite extensively in the southwestern part of the United States. Although sorghum is a drouth-tolerant crop, it grows well in the Southeast and other humid areas of the United States. Grain sorghum is chiefly used as feed for poultry, swine, cattle and other livestock. The grain, which contains about 12 percent protein, 3 percent fat and 70% carbohydrates compares favorably with corn as a feedstuff. The sorghum grain can be substituted for corn, but present sorghum varieties, like white corn, contain no vitamin A.

Grain sorghum can be grown successfully in Florida if the following management program is followed. It should receive the same fertility program recommended for corn (2). Land to be used for the production of grain sorghum must be limed. Seed must be treated for soil borne insects and diseases before planting. Insect control is necessary when the grain is in the milk to early dough stages. Plantings must be made by July 1 so that harvest can be made prior to the arrival of large flocks of blackbirds around November 1.

According to Quinby *et al.* (4), the four Dekalb hybrids, D-50a, E-56a, F-62a, and C-44a as well as Amak R-10 yield about 25 percent more grain than the Martin variety. It is assumed that hybrids will eventually replace open pollinated varieties, but until the grower accepts hybrids some open pollinated varieties will be grown. Hybrids are being produced to meet varying climatic conditions, but the most acceptable hybrid in a particular area may not necessarily be the highest yielding. The type of head, standability and ease of threshing must be considered in choosing a hybrid. Shane (6) reported 110 bushels of grain from Dekalb D-50a with several hybrids producing yields exceeding 100 bushels at Lexington, Kentucky.

Stickler and Laude (7) found that in Kansas the yield of grain sorghum was higher when the plant population per acre was 78,000 plants than when it was 52,000 plants. Row width differences did not affect yields greatly. Porter *et al.* (3) reported that in Texas higher sorghum grain yields were obtained in 12 and 20 inch rows than in 30 and 40 inch rows when grown under irrigation.

The many diseases and insects that attack grain sorghum are listed by Quinby *et al.* (4). Some insects infest the soil and destroy the sorghum

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plants by eating roots and germinating seed while some attack the plant above ground by eating stems, foliage or seed or by sucking the juices from the plant or developing seed. Insect control is essential in the production of grain sorghum and is profitable even though it is not a "high value crop."

The Florida Annual Crop Survey Summary of 1959 does not list any acreage of grain sorghum for Florida. Poor yields which have resulted from the lack of knowledge of cultural practices and insect control necessary for grain sorghum production are the reasons why no interest has developed in grain sorghum in Florida. Yields comparable to corn can be obtained with good management practices and insect control.

METHODS

The variety trials for 1958 were conducted on limed and unlimed areas. The limed areas had one ton of dolomitic lime in the fall of 1949 and 1.5 tons in the spring of 1952. In the 1959 and 1960 variety trials, the unlimed plots were eliminated. The plots were fertilized with 600 pounds of 4-12-12 per acre and sidedressed with 200 pounds of ammonium nitrate per acre. The yields were calculated on grain at 15% moisture and 56 pounds per bushel.

Calcium and potassium were extracted using neutral normal ammonium acetate according to Schollenberger and Simon (5). The model B Beckman Spectrophotometer was used for the calcium and potassium determinations. Phosphorus was determined from the strong extracting solution recommended by Bray and Kurtz (1).

Samples having a soil-water ratio of 1:1.5 were allowed to stand for one hour and then the pH was determined by using a Beckman pH meter.

RESULTS AND DISCUSSION

Grain sorghum variety testing was begun in West Florida in the spring of 1957. The stand was extremely poor and no yields were taken. The poor stand resulted from planting untreated seed which allowed a root rot infection in the seedlings and destruction of most of the plants. It is not known just which organism caused the disease, but there are several known root and seedling diseases of grain sorghum. With one exception, there was no trouble from seedling diseases in the variety tests in 1958, 1959 and 1960 after seed treatment. The variety test in 1958 was planted on limed and unlimed soil with four replications of each variety. Some injury was observed on young seedlings and a reduced vigor in all plants grown on the unlimed soil, whereas, no injury was observed on the limed soil. Even with the severe insect damage that was encountered in 1958, there was a fifty percent increase in yield of grain as a result of lime (Table 1). The variety tests for 1959 and 1960 were moved to other areas so that unlimed soils were not included in the test. The increased yields for 1959 and 1960 shown in Table 1 were a result of better insect control rather than better fertility.

In the spring of 1960, a date of planting and nitrogen study was begun on the same area on which the 1958 grain sorghum variety test had been planted. The first plantings were made April 1, 1960. It was observed that there was a reduced vigor of the plants grown on the unlimed soils

TABLE 1.—GRAIN SORGHUM VARIETY YIELDS FOR 1958-60.

Variety	Yield in Bushels Per Acre				
	1958		1959	1960	
	Unlimed	Limed	Limed	Limed	Average[1]
D-50a	24[2]	36	69	63	56
E-56a	21	33	35	42	37
Amak R-10	35	40	49	51	47
Amak R-12	24	34	51	39	41
Texas 610	31	42	53	46	47

[1]Average is for limed values.
[2]Each value is average of four replications.

of the bi-weekly plantings. In the June 15th plantings, it was found that many of the young seedlings on the unlimed soil died because of some disorder that appeared to be root rot. The young seedlings on the limed soil grew vigorously without any of the symptoms which were found on the young plants growing in the unlimed soil. It is evident that some factor other than the unlimed condition accentuated the condition of the affected seedlings. It may be noted in Table 2 that the rainfall was very deficient the month preceding the June 15th date of planting. It is believed that the root rot was intensified by low moisture conditions on the unlimed soil. The soil reaction and nutrient status is shown in Table 3 which indicates that lime is the only deficient nutrient in this fertility program for grain sorghum production.

TABLE 2.—RAINFALL DATA AT THE WEST FLORIDA EXPERIMENT STATION FOR THE PERIOD MARCH 1-AUGUST 1, 1960

Dates Observed		Rainfall in Inches
March	1-15	3.80
	16-31	2.21
April	1-15	8.57
	16-30	.01
May	1-15	4.18
	16-31	.81
June	1-15	.55
	16-30	1.78
July	1-15	3.63
	16-30	1.83

TABLE 3.—THE SOIL REACTION AND NUTRIENT STATUS OF SOIL FROM THE GRAIN SORGHUM DATES OF PLANTING EXPERIMENT

	pH	Pounds per Acre		
		CaO	K_2O	P_2O_5
Limed[1]	5.5[2]	1702	185	302
Unlimed	4.9	695	152	373

[1]Limed soil had one ton of dolomitic limestone in the fall of 1949 and one and one-half tons in the spring of 1952.
[2]Each value is the average of nine replications.

In 1960 field plantings of D-50a, E56a, Amak R-10, Amak R-12 and Texas 610 grain sorghum hybrids, the yields were 40, 50, 50, 60 and 60 bushels per acre, respectively. D-50a was blown down by high winds which contributed to its low yield. The other varieties show higher yields than were obtained in the variety trials (Table 1). This can be attributed to better insect control obtained on larger plantings of grain sorghum.

In the grain sorghum variety trials in 1958, severe insect damage was observed in the heads of maturing grain sorghum. The grain was being

eaten by larvae identified as the sorghum webworm, *Celama sorghiella*.[3] The larvae have numerous spines and hairs and are greenish with four red or brown longitudinal stripes. These insects must be killed or they will rapidly destroy the entire grain sorghum planting.

The corn ear worm, *Heliothis zea* is very prevalent and damages the crop either as the bud worm or by eating the grain from maturing heads.

In 1960, in a small area used for the dates of planting and nitrogen study on grain sorghum, severe damage resulted from an infestation of other insects. Because the area involved was rather small and the dates of planting were only two weeks apart, reinfestation was probably very rapid. Very poor control was obtained by using a mixture of malathion and toxaphene in repeated applications.

The southern false chinch bug, *Nysius raphanus* was identified as one of the insects causing the severe damage to the grain sorghum. The insects resemble chinch bugs and possess their characteristic odor but are smaller and more slender. They infest developing heads and grain and suck the plant juices from them thus causing poorly developed kernels. These insects do not normally do extensive damage in large plantings.

The rice stink bugs, *Solubea pugnax* were numerous and caused considerable damage to the sorghum by sucking the juices from the grain in the milk stage.

The rice weevils, *Sitophilus oryza* were quite prevalent in the maturing heads of the sorghum. This insect, which is considered to be a pest more often around storage areas, seemed to have done considerable damage in the field.

All of the insects included in this report have been found to be serious pests in grain sorghum production. These insects can be controlled with several insecticides but caution must be observed in choosing the insecticide to be used where grain is to be fed to dairy animals, poultry, swine or beef animals for slaughter.

SUMMARY AND CONCLUSION

Grain sorghum has a future as a source of grain in Florida because it fits well into a combine type of farming. Grain sorghum can be double cropped in rotation with small grain. There is a possibility that two crops can be obtained from one planting of grain sorghum by planting early and fertilizing the stubble. It can be planted after a corn failure is evident. This planting would be made in late June and would allow ample time for grain sorghum to mature.

Liming and a good insect control program are necessary in grain sorghum production.

In a research program, variety tests, fertility experiments or other research utilizing small areas of sorghum, the planting must be surrounded by a field planting to eliminate differences due to reinfestation of insects around the boundary of the planting. Variety tests should be segregated so that the dates of maturity for the varieties in a particular test are not too varied. This will aid greatly in obtaining better insect control.

[3]The author wishes to thank Dr. A. N. Tissot and Dr. L. C. Kiutert for identifying the insects mentioned in this article.

LITERATURE CITED

1. Bray, R. H. and L. T. Kurtz. Phosphorus. Soil Sci. 59: 39-45. 1945.
2. Hutton, C. E., H. W. Lundy and W. K. Robertson. Managing West Florida soils for high corn yields. Florida Agr. Exp. Sta. Cir. 76. 1954.
3. Porter, K. B., M. E. Jensen, and W. H. Sletten. The effect of row spacing, fertilizer, and planting rate on yield and water use of irrigated sorghum. Agron. Jour. 52: 431-436. 1960.
4. Quinby, J. R., N. W. Kramer, J. C. Stephens, K. A. Lahr, and R. E. Karper. Grain sorghum production in Texas. Texas Agr. Exp. Sta. Bul. 912. 1958.
5. Schollenberger, C. J. and R. H. Simon. Determination of exchange capacity and exchangeable cations in soils—ammonium acetate method. Soil Sci. 59: 13-24. 1945.
6. Shane, J. F. Results of the Kentucky grain sorghum performance tests. Texas Agr. Exp. Sta. Prog. Rep. 85. 1959.
7. Stickler, F. C. and H. H. Laude. Effect of row spacing and plant population on performance of corn, grain sorghum and forage sorghum. Agron. Jour. 52: 275-277. 1960.

Comparison of Summer Cover Crops For Effect On Populations Of Subterranean Insect Pests Associated With Corn[1]

EMMETT D. HARRIS, JR.[2]

The entomologist often finds it difficult or nearly impossible to determine if a heavy population of soil insects is present before conducting a chemical control experiment. Sampling techniques are laborious and few samples can be handled in a short time. Experiments may be initiated only to find later that the soil insect infestation is not great enough to compare treatments. It is highly desirable to conduct soil insect control studies on land which has not been previously or recently treated with soil insecticides. This results in a scarcity of land available for such experiments.

The farmer often applies soil insecticides as an insurance measure without knowing that a damaging population of soil pests is present. Knowledge of the effect of summer cover crop on populations of soil insects may be of value to the entomologist and the farmer.

Wilson (2) stated that *Melanotus communis* (Gyll.) was the most prevalent wireworm species in the Everglades and that other species present were *Heteroderes (Conoderus) laurentii* Guer., *Glyphonyx recticollis* (Say), *Aeolus dorsalis* (Say), *Dolopius* sp. and *Conoderus* sp. Wilson (3) reported that *M. communis* and *C. laurentii* were the only species present that were reported to be of economic importance in other sections of the United States. Kulash and Monroe (1) have since reported *Glyphonyx recticollis* (Say) as one of the species damaging corn in North Carolina. Wilson (3) reported data that indicated a large increase in wireworm populations during the summer of 1940 in plots containing grass and weeds, a slight increase in plots planted to soybeans, and a decrease in plots planted to cowpeas, velvet beans, or left fallow. In 1941 there was a decrease of wireworms in plots containing grass and weeds, about equal increase among plots planted in soybeans, cowpeas, or velvet beans.

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and less increase in fallow land. In 1942, there was an increase in wireworm population in grass and weed plots and a decrease in fallow land; data for the legumes was not given. Wolfenbarger (4) reported that damage by *M. communis* to potatoes in plots that had been planted to summer cover crops of sesbania, velvet beans, sesbania plus velvet beans, or buckwheat was significantly less than where natural grass and other plants had grown during the summer. Summer fallowed plots had the lowest percentage of wireworm damaged potatoes.

The purpose of this study was to compare summer cover crops of Sart sorghum, Sart sorghum plus Brabham cowpeas, Cornfield pumpkin, and cattail millet, alone and with Cornelli 54 field corn, for effect on wireworm populations in organic soil during the succeeding fall.

PROCEDURE

The field in which this study was conducted had not been treated with any insecticide for at least five years and during most of this time had been in a natural cover consisting mostly of goosegrass, *Eleusine indica* (L.) Gaertn., nutsedge, *Cyperus* spp. and spiny amaranth, *Amaranthus spinosus* L. Dimensions were 600 feet from north to south and 240 feet from east to west. A split-plot design in which whole plots contained corn or no corn was used. Each whole plot was 100 be 240 feet and the two whole plot treatments were replicated three times. The cover crops were planted in sub-plots that were 50 x 120 feet. Each whole plot contained 4 sub-plots.

Field corn and the summer cover crops were planted in rows that were 36 inches apart, 50 feet long, and ran from north to south. Field corn and sorghum were seeded at about 15 pounds per acre. About 45 pounds of cowpeas and 10 pounds of millet were planted per acre. Three pumpkin seed were placed in hills that were six feet apart within the rows. Field corn and cowpeas were planted on April 28; sorghum, millet, and pumpkin were planted on April 28, 1958. This field was plowed during the latter part of August.

On October 21, two columns of four rows of Golden Security sweet corn were planted so that each sub-plot contained four rows that were 50 feet long. Observations during the growth of this corn detected no plants that showed above ground symptoms of attack by soil insects. From December 1 to 23, five plants were pulled in each sub-plot and the roots and adhering soil examined for subterranean insects. Three whole ears of spoiled corn were buried to a depth of 6 to 8 inches in each sub-plot on December 3, 1958. Each ear and the soil within a radius of 2 to 3 inches was examined for subterranean insects on December 31.

RESULTS

Cucumber beetle larvae, *Diabrotica* sp. (probably *balteata* Lec.) were taken on corn roots, but not at spoiled corn traps. The summer cover crops did not differ significantly in the numbers of individuals that were found. There was an average of 21.6 grubs per sub-plot where no field corn had been planted and 11.0 grubs per sub-plot where field corn had been planted. The difference was not significant.

The number of *M. communis* grubs per sub-plot was higher where no field corn had been planted, but not significantly so (Figure 1). More

of these wireworms were collected from spoiled corn traps than from corn roots, but the methods of collection were not significantly different (Figure 2). Cowpeas plus sorghum resulted in significantly more *M. communis* wireworms than sorghum, which in turn resulted in significantly more than pumpkin or millet. There was a significant interaction between corn versus no corn and the cover crops. This interaction may have been caused by field corn resulting in a slightly greater population than no corn in pumpkin plots, but a smaller population in plots planted to the other cover crops. There was a highly significant interaction between method of collection and cover crops. Sorghum and sorghum plus cowpeas differed greatly with the spoiled corn trap collections but very little with the collections from sweet corn roots. The two methods of collection differed little in millet and pumpkin plots but greatly in plots planted to sorghum and sorghum plus cowpeas.

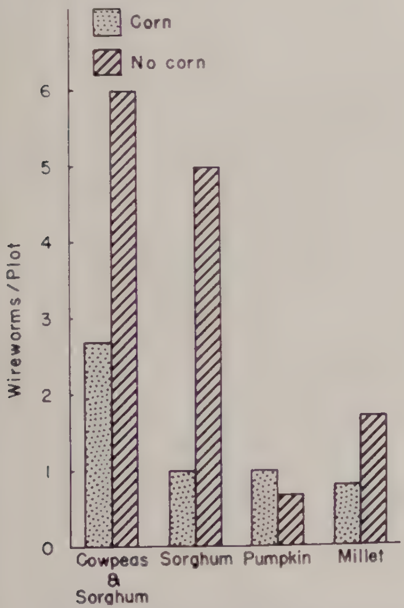

Fig. 1.—Effect of field corn and summer cover crops on the numbers of *Melanotus communis* (Gyll.) larvae collected per plot.

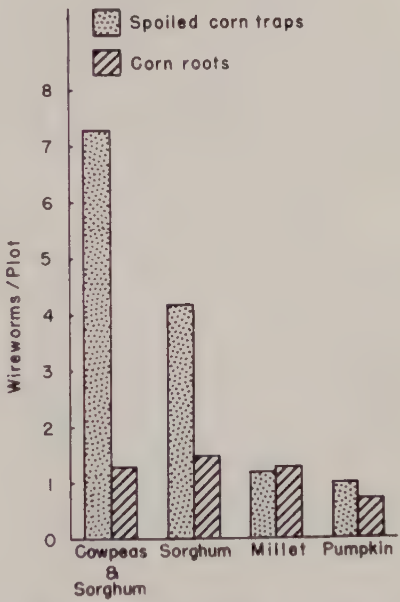

Fig. 2.—Effect of method of collection and summer cover crops on the numbers of *Melanotus communis* (Gyll.) larvae collected per plot.

There were slightly more *Conoderus* sp. (probably *difformis* Fall) wireworms where field corn had not been planted, but the difference between corn and no corn was not significant (Figure 3). The methods of collection did not differ significantly, although more larvae were collected from corn roots than from spoiled corn traps (Figure 4). There were no significant differences among the cover crops.

Corn did not differ significantly from no corn in respect to the numbers of *Glyphonyx* (probably *recticollis* (Say)) wireworms that were collected (Figure 5). There was a significant interaction between corn vs. no corn and the cover crops. With cowpeas plus sorghum, there was a lower popu-

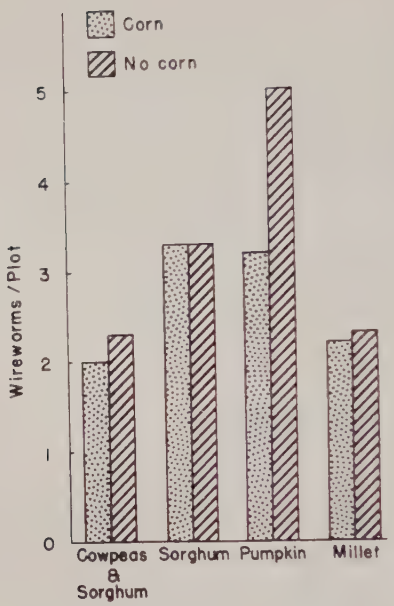

Fig. 3.—Effect of field corn and summer cover crops on the numbers of *Conoderus* sp. larvae collected per plot.

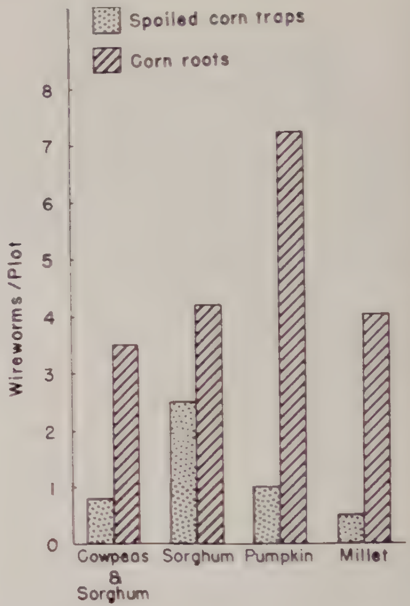

Fig. 4.—Effect of method of collection and summer cover crops on the numbers of *Conoderus* sp. larvae collected per plot.

lation of these larvae where field corn had been planted. With the other cover crops, corn resulted in a greater population. When not planted with corn, cowpeas plus sorghum resulted in a significantly greater population than the other cover crops. This was not true when the cover crops were planted with corn. The difference between the collection methods was not significant, although more individuals were taken from corn roots (Figure 6). Cowpeas plus sorghum resulted in significantly more *Glyphonyx* larvae than sorghum, pumpkin, or millet.

DISCUSSION

Differences between methods of collection and between field corn and no field corn were often large but not significant. This probably resulted from a deficiency in replication of the whole plots and uneven population distribution of the soil insects.

Although differences were not significant, more *M. communis* and *Conoderus* sp. larvae were found where no field corn had been planted with the summer cover crop. This probably was caused by preference of ovipositing females, or by larvae continuing to feed on field corn residue in the soil instead of moving to sweet corn roots or spoiled corn traps. Cowpeas plus sorghum resulted in greater populations of *M. communis* and *Glyphonyx* sp. larvae than sorghum, pumpkin, or millet. This may have resulted from an actual preference of adult females for cowpeas, or from greater protection or shading from the thicker cover provided by cowpeas.

Although *M. communis* had been considered to be the most economic-

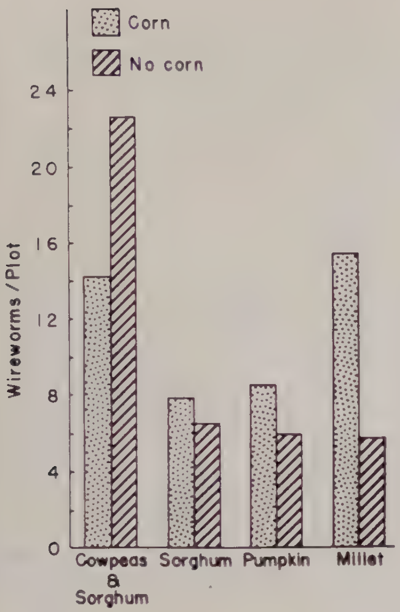

Fig. 5.—Effect of field corn and summer cover crops on the numbers of *Glyphonyx* sp. larvae collected per plot.

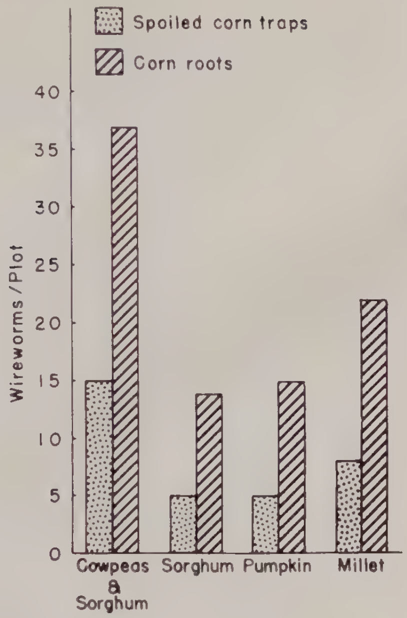

Fig. 6.—Effect of method of collection and summer cover crops on the numbers of *Glyphonyx* sp. larvae collected per plot.

ally important wireworm in the Everglades, *Conoderus* sp grubs were collected in about equal numbers, and *Glyphonyx* sp. larvae were collected in much larger numbers from about corn roots. The *Glyphonyx* grub is much smaller and probably causes less damage per individual. *M. communis* and *Conoderus* larvae seemed to feed more on the underground portion of the stalk, whereas *Glyphonyx* larvae seemed to be true root feeders. A difference in food preference might be indicated by the fact that *M. communis* was collected more often from spoiled corn traps, whereas the other two wireworms were more frequently collected from corn roots.

The presence of a fairly large population of subterranean pests with no apparent above ground symptoms of attack among the sweet corn plants might suggest an effect of other environmental factors on the severity of plant resonse to attack of soil insects.

Acknowledgements. The author thanks Mr. A. B. Jimmerson, Mr. Robert Kent, and Mr. C. E. Seiler for help in conducting this experiment, Mr. Edward King, Jr. for preparing the graphs and Mr. Ronald Jones for photography.

LITERATURE CITED

1. Kulash, Walter M. and Robert J. Monroe. Field tests for control of wireworms attacking corn. Journ. Econ. Ent. 48 (1): 11-19. 1955.
2. Wilson, J. W. A preliminary report on wireworm investigations in the Everglades. Fla. Entomologist 23 (1): 1-26. 1940.
3. Wilson, J. W. Present status of the wireworm problem in South Florida. Proc. Fla. State Hort. Soc. 59: 103-106. 1946.
4. Wolfenbarger, D. O. Biology and control of insects affecting winter vegetable crops. Florida Agr. Expt. Sta. Annual Report pp. 260-261. 1949.

A Report of Several Experiments Studying Ecological And Physiological Problems Related To Maximum Corn Production In Florida

GORDON M. PRINE[1]

INTRODUCTION

In recent years there has been much interest in determining the maximum potential production of corn. In 1955, Lamar Ratliff (3), a Mississippi farm boy, produced the outstanding corn yield of 304 bushels per acre. Numerous farmers and investigators in widely varying locations in the United States have reported yields of 200 bushels or more per acre. In 1959, The Haufler Brothers of Alachua County, Florida, without irrigation, produced 162 bushels of corn per acre. Extremely high yields of corn are possible and it is a great challenge to the Agricultural Scientist to study and determine the factors necessary for these high yields of corn. The purpose of this paper is to discuss some of the environmental factors limiting maximum corn production and to report results of several experiments designed to study certain of these factors affecting corn production.

NECESSARY FACTORS FOR MAXIMUM CORN PRODUCTION

Population: What are some of the conditions under which a corn plant must perform in order to make 200 or more bushels of corn per acre? The first thing to be considered is the population of corn plants per acre. In Table 1, data are presented showing the area and the soil volume to 2 and 5 foot depths for each plant at different populations. In Table 2, similar data are presented for total solar radiation per plant over a 60 day period at Gainesville, Fla., and the glucose sugar that could be synthesized from one percent of this radiant energy. As the population increases the competition between plants becomes more intense for space, light, plant nutrients, water and other factors of plant growth. The dry matter yield of grain per plant needed to produce 200 bushels of corn per acre at various populations is given in Table 2. Most hybrid corn plants do not normally produce the 1.93 pounds of dry grain per plant needed at 5000 plants per acre to make 200 bushels of corn per acre even under the best environmental conditions. The prolific hybrids of the South tend to produce more than one ear per stalk and ears are relatively small. Plants of the locally adapted hybrids, Florida 200 and Dixie 18 corn, would be considered to be well developed if they produced two ears in which the total dry matter of grain and cob was .80 pound. It would take 15000 such plants to the acre to make 200 bushels of corn per acre. Ordinarily such plant development is only found at lower populations.

What avenues of approach are open to the research worker to improve yields of individual corn plants of prolific hybrids such as just described so yields of 200 bushels or more could be obtained? The first avenue is to try to make the plant environment at the higher populations equally

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TABLE 1.—THE SOIL AREA AND SOIL VOLUME PER PLANT AT TWO DEPTHS FOR DIFFERENT POPULATIONS OF CORN.

Plants per acre	Level soil surface area per plant	Soil volume per plant 2 ft. depth	5 ft. depth
1000's	sq. ft.	cu. ft.	cu. ft.
5	8.7	17.4	43.6
6	7.3	14.5	36.3
7	6.2	12.4	31.1
8	5.5	10.9	27.3
9	4.8	9.7	24.2
10	4.4	8.7	21.8
11	4.0	7.9	19.8
12	3.6	7.3	18.2
13	3.4	6.7	16.8
14	3.1	6.2	15.6
15	2.9	5.8	14.5
16	2.7	5.5	13.6
17	2.6	5.1	12.8
18	2.4	4.8	12.1
19	2.3	4.6	11.5
20	2.2	4.4	10.9
25	1.7	3.4	8.7
30	1.5	2.9	7.3

favorable to that at lower populations so production per plant would remain the same. A second approach would be to change the genetic makeup of plants so they would give the same performance per plant at much higher population densities than at the present. Still another approach would be to genetically increase grain yield per plant at low populations until individual plant yields are sufficient to make desired yields. Probably the desired goal will be attained only through some combinations of the above three approaches. This paper will dwell on the first approach suggested above; namely to try to make the environment more favorable for corn growth at higher populations.

Nutrients: First, it seems practical to theorize where progress can be made in modifying the plant environment. A logical beginning is to consider the plant nutrition. If the plant population is doubled from 8000 to 16000, and the same individual plant performance is expected, then the total amount of nutrients should be doubled to provide each plant with the same amount of nutrients. It is not possible to double all factors of soil fertility, but it is possible to apply needed nutrients as fertilizer. Large amounts of nutrients are needed to make high yields (See Table 3.). At the high rates of fertilizer needed to furnish nutrients for very high yields of corn, one can expect trouble from such things, as excessive salt concentration, antagonism of elements, toxicity, and higher leaching rates. While more research is needed, it seems probable that the problem of adequate plant nutrients at high populations can be solved satisfactorily.

Water: What can be done about available water supply? Changing the amount of available water holding capacity of soils would be expensive and impractical. The alternative is irrigation when rainfall is inadequate and drainage when rainfall is excessive. Together, proper drainage and irrigation offer a means of solving the water problems of the high producing corn crop.

TABLE 2.—THE AVERAGE SOLAR ENERGY RECEIVED PER PLANT DURING AN AVERAGE 60 DAY PERIOD AT GAINESVILLE, FLA. FOR VARIOUS POPULATIONS OF CORN AND THE GRAIN YIELD PER PLANT NEEDED TO MAKE 200 BUSHELS OF CORN PER ACRE.

Plants per acre	Solar energy per plant for 60 days[1]	Glucose per plant possible from 1% utilization of solar energy for 60 days[2]	Dry matter yield per plant needed for 200 bushels per acre[3]	
			Grain	Grain plus cob
1000's	1000 kg. cal.	lbs.	lbs.	lbs.
5	267	1.58	1.93	2.41
6	222	1.31	1.61	2.01
7	190	1.12	1.38	1.72
8	167	.98	1.21	1.51
9	149	.88	1.07	1.34
10	134	.79	.96	1.20
11	121	.72	.88	1.09
12	112	.66	.80	1.00
13	103	.61	.74	.93
14	95	.56	.69	.86
15	89	.52	.64	.80
16	83	.49	.60	.75
17	79	.46	.57	.71
18	74	.44	.54	.67
19	70	.41	.51	.64
20	67	.39	.48	.60
25	53	.31	.39	.48
30	45	.26	.32	.40

[1]Total solar energy was calculated by multiplying the soil surface area per plant in cm.[2] x 60 days x 550 cal. per cm.[2]. The average daily solar energy for Gainesville, Fla. during the period from April through middle of July is approximately 550 cal. per cm.[2].

[2]Total kilogram calories of solar energy per plant for 60 days period at 550 cal. cm.[2] per day x .01 x 180 gms. in mole of glucose

453.6 gms./lb. x 673 kg. cal./mole of glucose

[3]Corn was considered to have 14% moisture content.

Temperature: Soil and air temperatures would differ at high and low populations. The temperatures of lower populations would tend to be higher in daytime and lower at night. However, the overall difference in temperatures would usually be small, especially where adequate soil moisture is maintained.

Carbon dioxide: Corn production could be limited by carbon dioxide at high populations and probably is on occasion. Schroder has measured up to a 6% decrease from normal carbon dioxide level within a well fertilized and irrigated Dixie 18 corn field at a population of 18000 plants per acre.[2] However, the measured decreases in carbon dioxide content were only for a minute or so. The slightest breeze was instrumental in returning CO_2 within the corn to normal. Apparently diffusion and wind movement effectively replenish carbon dioxide used by plants under most circumstances, so it is quite probable that factors other than carbon dioxide

[2]Schroder, Vincent N. Unpublished Data. Department of Agronomy. Florida Agr. Exp. Sta. Gainesville, Florida.

TABLE 3.—THEORETICAL QUANTITIES OF MAJOR PLANT NUTRIENTS NEEDED FOR PRODUCTION OF HIGH YIELDS OF CORN GRAIN AND STOVER.[1]

Yield per acre	Pounds per acre			
	N	P_2O_5	K_2O	Total
60 bu. grain	57	23	15	95
2 tons stover	38	12	55	105
Both	95	35	70	200
120 bu. grain	114	46	30	190
3 tons stover	57	18	83	158
Both	171	64	113	348
180 bu. grain	171	69	45	285
4 tons stover	76	24	110	210
Both	247	93	155	495
240 bu. grain	228	92	60	380
5 tons stover	95	30	138	263
Both	323	122	198	643

[1]Based on nutrient content of corn as given by Collings (2).

are now limiting corn yield. Beyond adding organic matter to soil to increase soil respiration, very little can be done practically to rectify a carbon dioxide deficiency to corn plants.

Light: As the plant population increases, the amount of available radiant energy per plant decreases (Table 2). There is no economical way to maintain the light energy per plant as population increases. Often over the life cycle of an annual plant less than one percent of the total radiant energy available to the plant is actually utilized by the plant. Corn plants making maximum production must be much more efficient than one percent in converting light energy into the finished plant product. Seventy-five percent of the dry matter of the corn plant may be produced the last 60 days of the life cycle of most adapted corn in Florida. Under average light conditions at Gainesville it would take 1.25% efficiency in utilization of light energy for a 60 day period just to make glucose equivalent to the weight of corn grain needed to make 200 bushels of corn per acre.

During the eight week period from May 13 to July 8 in 1960, at Gainesville, the stalk and leaf weight of Florida 200 corn plants seeded at 15000 plants per acre increased in weight by .70 pound and produced ears of corn weighing .54 pound. This was a total increase in dry matter of the top portion of plant of 1.24 pounds. Converting this dry matter to glucose in the manner used by Terrien *et al.* (4) the dry matter would be equivalent to 1.46 pounds of glucose. Adding in a value of 25% of fixed glucose, as suggested by Transeau (5) as a good estimate of respiration, the total amount of glucose manufactured during the eight week period would be 1.82 pounds of glucose per plant. The average daily solar radiation measured by an Eppley pyrheliometer at Gainesville during the eight week period was 605 Langleys (gm. cal. $cm.^{2}$).[3] The energy needed to synthesize the glucose fixed per plant through photosynthesis was equivalent to 3.3% of the measured solar energy. The rate of yield per acre of

[3]Climatological Data National Summary. U. S. Weather Bureau. Vol. 11. 1960.

these selected plants was 135 bushels. To give a yield of 200 bushels per acre plus respiration at same stalk size, would have required another .7% increase in utilization of the light energy for a total efficiency of 4.0%. Very high efficiency in utilization of radiant energy to produce the finished plant product is a necessary requirement of the corn plants making 200 or more bushels of corn per acre and should be considered in corn breeding programs.

The intensity of light within a stand of corn is extremely variable due to many factors which can affect the light intensity. Population is one of these factors. Table 3 shows the range of light values from direct sunlight to the shaded portions of tall corn at different populations at 11:00 to 11:35 a.m. on a clear day in early July. These measurements are qualitative in nature but they do emphasize the variation in light intensity within corn stands. The readings show only indirectly the amount of sunlight passing unintercepted past the top leaves of corn plants to lower leaves and soil. The amount of unintercepted light varies throughout the day with the angle of sun. It is practically nil in the early morning and late afternoon and greatest at midday. The smaller the per acre population of plants of the same size the greater the amount of unintercepted sunlight.

Direct sunlight strikes only the very tops of corn plants in thick stands during the early morning and late afternoon. During these periods much of the plant is shaded and light intensities in shaded areas are low. Light intensity is especially low when a cloud covers the sun during these periods. This could be a very important consideration in Florida as afternoons are normally cloudy during the period when the corn plant is in fruiting stage.

Other Factors: For high production of corn or any crop, the diseases, insects, nematodes, weeds and other pests which might limit growth must be adequately controlled. Also the inheritant chemical, physical and biological properties of the soils which may limit production must be overcome. In fact, to obtain the maximum yields desired, all factors in the corn plants environment would have to be near optimum.

REPORT OF FIELD EXPERIMENTS

After consideration of the major environmental factors needed for the production of high populations of corn it appeared that light was probably an important limiting factor in Florida. This motivated the three field experiments reported in this manuscript for the direct and indirect purpose of improving light conditions to corn and studying the response of the corn plant to different light conditions.

Experiments 1, 2 and 3 were conducted adjacent to each other in 1960 on the same block of soil which was predominantly Arredondo fine sand. The three experiments were started at the same time and received similar management except for exceptions noted under materials and methods of the experiments. Management common to the three experiments is listed under Experiment 1. All rows were planted in north and south direction.

EXPERIMENT 1: KERNEL ORIENTATION OF CORN

Introduction: The leaves develop on the main stalk of a corn plant at approximately right angles to the flat side of kernel, when the pedicel

TABLE 4.—LIGHT INTENSITIES IN A FIELD OF TEN-FOOT TALL DIXIE 18 CORN AT GAINESVILLE, FLORIDA.[1]

Population (Plants/acre)	Row direction	Height of light measurements within corn (feet)	Light intensities in foot-candles: Outside corn 5 feet over-grass	In shade within corn
5000	N + S	0-3½	11000-12000	1000-1500
		3½-7	Same	1500-2500
	E + W	0-3½	Same	1400-2000
		3½-7	Same	1600-2500
9000	N + S	0-3½	Same	800-1000
		3½-7	Same	800-1200
	E + W	0-3½	Same	600- 950
		3½-7	Same	700-1250
13000[2]	N + S	0-3½	Same	720- 900
		3½-7	Same	800-1200
	E + W	0-3½	Same	800-1200
		3½-7	Same	1000-1400
17000[2]	N + S	0-3½	Same	500- 800
		3½-7	Same	600-1000
	E + W	0-3½	Same	600- 800
		3½-7	Same	700-1200

[1]Light intensity measurements were made on July 1, 1959 from 11:00 to 11:35 a.m. E.S.T. under a clear sky using a Weston illuminometer. Sensitive element of the illuminometer was horizontal to the ground during measurements. Several measurements were made for each condition and highest and lowest values recorded.

[2]Lower leaves of plants at these populations were no longer suspended across middles but hanging down by stalk.

or point of kernel is placed downward in soil. With the point downward, one can control at planting the direction of later leaf development by controlling the direction the flat side of kernel is placed. Research workers at the University of Illinois have reported a 2 to 23 bushels per acre increase in production of corn from orientation of kernels at planting so leaves of plants would grow at right angles to the row (1). This condition was more favorable than random planting for interception of light by plants. The greater shading of soil resulted in lower rates of soil moisture evaporation and less fluctuations in soil temperatures.

Materials and Methods: In 1959, Dixie 18 corn was planted at 17,000 plants per acre in 38-inch rows. Kernels were oriented as outlined in Table 5 so leaves would grow at random, along rows and across middles between rows. Two replications of each treatment were planted on April 9. The corn was uniformly heavily fertilized and irrigation was applied to supplement rainfall. Corn received a minimum of one inch of water every five days from just prior to tassel emergence to maturity.

In 1960, Florida 200 corn was planted at 9,000 and 15,000 plants per acre and kernels arranged in the same three ways as in 1959. Management practices given the corn grown in 1960 were as follows:

Date	*Management Given*
January 19	21 lbs./A of calcic limestone
February 9	600 lbs./A of 0-10-20
February 23	550 lbs./A of 4-8-16 containing 17.5 pounds of 25% chlorodane
February 26	fumigated row with one gallon per acre of 1,2-dibromo-3-chloropropane (Nemagon)
March 8	planted corn
March 9	sprayed 18″ band over row at rate of 2 lbs. of 50% Simazine per acre
March 23	30 lbs./A of N as sodium nitrate 42 lbs./A of K_2O as muriate of potash 3 lbs./A of P_2O_5 as superphosphate 33 lbs./A of MgSO 6 lbs./A of $ZnSO_4$ 4 lbs./A of $CuSO_4$ 25 lbs./ of complete fritted minor element mixture (Frit FN 501)
March 30	900 lbs./A of dolomitic limestone
April 11	first cultivation and 30 lbs./A of nitrogen as ammonium nitrate
April 18	second cultivation
April 25	74 lbs. N per acre on plots with 15,000 plants per acre only
April 26	third cultivation 30 lbs./N per acre as potassium nitrate 30 lbs./N per acre as ammonium nitrate 45 lbs./N per acre as urea

TABLE 5.—THE EFFECT OF KERNEL ORIENTATION ON THE GRAIN YIELD OF CORN DURING THE 1959 AND 1960 GROWING SEASONS AT GAINESVILLE, FLORIDA.

Kernel placed point down so flat side was:	Leaf growth was:	Plants per acre	Bushels of grain per acre	
			1959	1960
random	random	9000	------	107.1
right angle to row	along row	9000	------	106.5
parallel to row	across middle	9000	------	115.9
random	random	15000	------	113.8
right angle to row	along row	15000	----	103.8
parallel to row	across middle	15000	------	106.4
random	random	17000	82.0	-------
right angle to row	along row	17000	64.0	-------
parallel to row	across middle	17000	68.8	-------
L.S.D. .05 for kernel orientation			N. S.	N. S.
Replications			2	5

Total fertilization for 9,000 plants per acre was 188 pounds nitrogen, 107 pounds phosphoric acid and 279 pounds of potash. The 15,000 population had an additional 74 pounds of nitrogen per acre.

Beginning just previous to tassel emergence, the corn in Experiments 1 and 2 received supplementary irrigation. When a soil moisture deficit

of 1.25 inches occurred, sufficient irrigation water was applied to bring soil back to field capacity. Soil moisture deficit was estimated by a water balance method where daily evapotranspiration was considered to be .20 inch. The corn was irrigated six times for a total of 7.7 inches of water.

Plots of Experiment 1 consisted of six rows, 38 inches apart and 30 feet long in 1959 and 20 feet long in 1960. The four center rows were harvested individually for yield after removing 5 and 2 feet of border on each of the ends in 1959 and 1960 respectively. Treatments were arranged in a completely randomized block design both years.

Results and Discussion: The grain yields of kernel orientation treatments for 1959 and 1960 are given in Table 5. There was no significant difference between kernel orientation methods in either 1959 or 1960. There was also no significant difference between populations in 1960. There were many suckers on plants in 1960, especially at 9,000 population, and leaf arrangement of suckers was random. It is quite possible that any real difference between kernel orientation treatments was not revealed in 1959 because of the small number of replications plus considerable land variation and in 1960 because of non uniform suckering. This experiment was included in this paper to show that the problem of kernel orientation affecting yields of corn may be controversial and more careful research should be conducted on this problem before any conclusions are drawn.

EXPERIMENT 2: LEAF REMOVAL STUDY ON CORN

Introduction: The low light intensities measured around the lower leaves of corn plant in thick stands gave reason to suspect that the lower leaves were carrying on only low rates of photosynthesis and were contributing little or nothing to the development of the corn ear. In fact, it is possible that under cloudy conditions these lower leaves are not able to manufacture food needed for their living processes so food which might have gone to ear was being translocated to these leaves from higher leaves.

It was theorized that if the lower leaves of thickly planted corn were contributing little or nothing to the grain, then grain yields would not be reduced if these leaves were removed. A field experiment was conducted to study the effect on grain yields of removing lower leaves and leaves from other parts of the plant.

Materials and Methods: In 1960, Florida 200 corn was planted at 15,000 plants per acre and managed the same as corn at the same population under Experiment 1. However, all suckers were removed from plants early in the season so each plant had only the main stalk. Leaves were removed from corn plants by stripping, leaving the sheath. The number and location of leaves that were removed are given in Table 6. Leaves were removed when tassels began to emerge from the boot.

Treatments were replicated four times in a completely randomized block design. Plot size was 6 rows, 38 inches apart and 30 feet long. The yields were taken on a 20 foot section from each of the center four rows.

Results and Discussion: The grain yields of various leaf removal treatments are presented in Table 6. The check which had no leaves removed, gave the highest grain yield, 123 bushels per acre. Removal of the bottom five leaves reduced the yield 8 bushels per acre. As the corn plants normally had fifteen leaves, the removal of 33% of the leaves resulted in only a 6%

TABLE 6.—THE GRAIN YIELD OF FLORIDA 200 CORN PLANTS[1] PLANTED AT 15000 PLANTS PER ACRE WHEN LEAVES WERE STRIPPED FROM VARIOUS PARTS OF PLANT AT EARLY TASSEL STAGE.

Leaf removal treatment	Yield of ovendry corn bushels/acre
Check	123.1
Top five leaves removed (tassel and stalk remained)	97.5
Bottom five leaves removed	115.3
All leaves removed from one side of plant (7 or 8 leaves left per plant)	101.3
Cut top out of every other row below fifth leaf from top	109.4
a. Topped row	86.8
b. Normal row	132.8
L.S.D. .01	4.1

[1]The treated corn plants normally had 15 leaves, with an occasional plant having 16 leaves. The average plant height was 10.5 feet.

reduction in yield. This supports the theory that the lower leaves of corn plants planted in thick populations do little to increase grain yields.

Removal of the top one-third of leaves on corn plant resulted in a 21% reduction in yield below check. Ordinarily it might be expected that the top leaves would be the most active on the plant since they are younger and receive the most direct sunlight. The lower leaves, though apparently not as efficient as the top leaves, were still rather efficient in manufacture of plant food when more light was made available by removal of the topmost leaves. It seems likely that the superior development of individual corn plants in thin stands is due to high rates of photosynthesis in all parts of the plant shoot and not just in the topmost leaves. Perhaps the high efficiency of lower leaves during this experiment was related to the fact they were free of any leaf diseases or fertilizer deficiency symptoms and remained green and vigorous until plant maturity.

The removal of leaves from one side of corn plants resulted in removal of 8 leaves from some stalks and 7 leaves from others. However, the average was one-half of the leaves per plant. One-half of leaves left uniformly along the stalk gave 82% of the yield when all leaves were present. Removal of the leaves left space so more light could penetrate to the soil and lower leaves of the corn plants. When corn plants with half of their leaves removed during the grain producing period can make 100 bushels of grain per acre, there seems to be hope of making 200 bushels per acre using the entire plant.

The tops were cut from corn plants below the fifth top leaf of every other row in order to allow more light to penetrate to the lower leaves of the untopped row. The yield of topped row and untopped row together was only 89% of the check. However, the untopped corn yielded nine more bushels per acre than the check. The topped corn yielded less than the treatment where just the five top leaves were removed. The tassel, stalk and leaf sheaths of the latter treatment were apparently contributing to the higher yield obtained.

The excellent performance of the corn plants with large percentages of the leaves removed leads to reconsideration of the size of current southern

hybrids. Are large corn plants needed or can much smaller corn plants be developed to do the same job? Small plants, if they have the same efficiency in converting available light energy to plant food, would need less plant food than large plants for vegetative structure and respiration. If a part of the plant food going to make up unneeded vegetative structure of the large corn plant could be transferred to the ear of the small plant, this could greatly increase the grain producing potential of the small plants.

EXPERIMENT 3. CORN INTERCROPPED WITH PEANUTS AND SOYBEANS

Introduction: It has been a long established practice in the South to plant crops such as peanuts between rows of corn. Such a practice has nearly always proven beneficial to the corn. Since the widespread use of the farm tractor and heavy fertilization, the practice of intercropping between rows of corn has become less popular. Nevertheless, intercropping does have certain advantages. One is that both crops can use some of the space of the other crop and thus reduce competitive stresses if the life cycle of crops involved are sufficiently different that they do not overlap greatly with each other during their critical periods. Another advantage is that there is less chance of a total crop failure as environmental conditions are likely to be favorable for at least one of the crops in most seasons.

Materials and Methods: In 1960, Florida 200 hybrid corn was planted at populations and in rows according to treatments outlined in Table 7. The yield plots consisted of two rows 25 feet long and were replicated five times. The treatments were randomized in a block design and then a field plan developed to keep environment as near normal field conditions as possible. That is, corn in solid stand had at least two border rows between the yield rows and peanut or soybean rows to give environmental conditions more like a solid field of corn. Even these borders may not be wide enough when making a study where light is probably a major factor contributing to any differences.

The corn was planted and managed in the same manner as corn in Experiment 1 and 2 through April 18 (see Experiment 1). Fertilizer was broadcast uniformly over experimental area including peanut and soybean plots. On April 26 the third cultivation was given corn and 30 pounds of nitrogen per acre applied to 9000 plants per acre and 60 pounds

TABLE 7.—THE GRAIN YIELD OF FLORIDA 200 HYBRID CORN PLANTED IN SOLID STAND AND PLANTED BETWEEN ROWS OF SOYBEANS AND PEANUTS AT GAINESVILLE, FLORIDA IN 1960.

Row arrangement	Population (plants/acre)	Bushels per acre yield of ovendried corn: On corn area	On total land area
Solid corn	9000	101.0	101.0
Solid corn	18000	117.8	117.8
2 rows corn—2 rows soybeans	18000	145.2	72.6
2 rows corn 2 rows peanuts	18000	137.6	68.8

of nitrogen to 18000 plants per acre populations. Peanuts were planted April 15 and soybeans on June 15. Before soybeans and peanuts were planted the space between corn rows was given periodic shallow harrowing to control weeds.

The corn in this experiment was only irrigated once. Two inches of irrigation water were applied on May 24. The rainfall for the month preceding this irrigation date was only 1.21 inches and only .27 inch occurred during the 20 day period before the irrigation. The corn was in stage where only one or two tassels could be seen out of the boot. The corn was being seriously affected by drought at time of irrigation as wilted leaves had not recovered tugor overnight for several days. The drought continued for nine more days after irrigation was applied. The rainfall for May 1960 was only 1.20 inches. The irrigation water plus rainfall added up to the average normal rainfall for this month at Gainesville.

Results and Discussion: Yields of corn planted in solid stands and between rows of peanuts and soybeans are given in Table 7. The yields of grain at the 18000 plants per acre population between soybeans and peanuts were 44 and 36% respectively, higher than corn planted solid at a population of 9000 plants per acre. A portion of this increased yield was apparently from the increased population, because solid corn at 18000 plants per acre yielded 17% more than solid corn at 9000 plants per acre.

The solid corn at 9000 plants per acre and the corn between peanuts or soybeans at 18000 plants per acre had the same number of plants per acre if total land area was considered. The corn between interplanted rows of peanuts and soybeans yielded 68 and 72% as much as solid corn at 9000 plants per acre. It was hoped that yields of corn planted at twice the normal population between rows of peanuts or soybeans would give 85% or more of the production on an acre of land as the normal population planted in solid stands. Perhaps this goal can be obtained under more ideal conditions. The fertilizer through April 18 was applied uniformly to the experimental area. This meant that corn between peanuts and soybeans could not get the same amount of fertilizer nutrients per plant as solid corn without getting one-half of the nutrients from the peanut and soybean areas. Thus the corn plants between peanuts and soybeans could have had nutrient deficiencies.

The corn between soybeans and peanuts seemed to suffer more from drought than solid corn. Apparently greater reflection of radiant energy from the bare soil in the peanut and soybean areas made more energy available for evapotranspiration from the neighboring corn. Also the soil and air temperature would have been higher in the unshaded bare soil areas contributing to more favorable conditions for dessication of the corn between peanuts and soybeans.

SUMMARY AND CONCLUSIONS

Some of the environmental factors affecting the maximum grain yields of corn are discussed. It was concluded that light is probably a serious limiting factor for high yields and one very difficult to do anything about.

Three experiments with corn are described. In Experiment 1, the effects of placement of kernel on corn production were studied. There was no significant difference between three different ways of kernel placement, (1) random, (2) kernel with point downward and flat side parallel

to row, and (3) kernel with point downward and flat side perpendicular to row.

In Experiment 2, the effect of removing leaves from various parts of Florida 200 corn plants in a population of 15000 plants per acre was studied. Removal of the bottom-one-third of leaves, top one-third of leaves and one-half of leaves from along one side of the plants resulted in yield reduction of 6, 21 and 18% respectively, below the 123 bushel yield of the check.

In Experiment 3, corn was planted in solid stand and between rows of peanuts and soybeans. Corn planted on half the space but the same population per acre between rows of peanuts and soybeans yielded 68 and 72% respectively, as much grain as the solid corn.

Where light intensity conditions around the lower portions of corn plants was enhanced, plant performance was usually improved. Efficiency in utilization of light energy should be considered in breeding and culture of corn for maximum production. There is only so much solar energy reaching a unit of area whether the grain yield is high or low so plants producing high yields must use the light energy efficiently.

LITERATURE CITED

1. Anonymous. Orientation corn planting saves moisture. Crop and Soils 11: (8) 22. 1959.
2. Collings, G. H. Commercial Fertilizers. 4th Edition. The Blakiston Company. Philadelphia, Pennsylvania. p. 417. 1940.
3. Ratliff, L. 304.38 Bushels from one acre. Breeders Gaz. 120 (11): 5. 1955.
4. Terrien, J. G. Traffaut, and J. Carles. Light, Vegetation and Chlorophyll. (Translated by M. E. Thompson). Philosophical Library, Inc. New York, New York. p. 207. 1957.
5. Transeau, E. N. The accumulation of energy by plants. Ohio Jour. Sci. 26: 1-10. 1926.

Date of Planting X Variety Interactions In Grain Sorghum[1]

A. J. NORDEN[2]

The acreage of sorghum harvested for grain or seed has been increasing steadily in Florida since 1940. Grain sorghum and corn are chemically similar and about equal in feeding value. Sorghum is better adapted to withstand periods of drought than corn. However, in Florida, unpredictable yields, susceptibility to certain insects and diseases, and harvesting difficulties have discouraged widespread production of this crop.

A knowledge of the interaction of any species with the environment in a new area of production is basic to a cultural scheme that will result in maximum yields. The experiments reported in this paper were designed to determine the yield, plant height and maturity response of grain sorghum varieties planted on different dates under conditions relatively favorable for plant growth.

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REVIEW OF LITERATURE

Date of planting studies with grain sorghum have been conducted in the various grain sorghum producing regions of the United States. Karper *et al.* (4) found that grain sorghums have a rather definite optimum time of planting in the different regions of the state of Texas. Several investigators (4, 5, 8) have found that changing the planting date affected the number of days to maturity, with later plantings generally maturing in a shorter period. Lower temperatures which retarded growth in early plantings were considered partially responsible for delayed maturity.

The number of days from planting to heading were found to be decreased with delayed planting (1, 2, 4). Garner and Allard (3) showed that length of day or photoperiodism has a marked effect on the growth and flowering of many plants, including sorghum, but that the full expression is conditioned on the specific requirement of the particular plants in question as to temperature and other environmental effects. Cushing *et al.* (2) suggested that lower temperatures at earlier planting dates increased the number of days to heading but that changing length of day also had an effect. Ross and Webster (6) stated that daylength during the first five weeks after planting largely determines heading.

Various investigators (2, 5, 8) observed that grain sorghum plants tend to be taller in later plantings; however, Karper *et al.* (4) reported little difference in the average plant height at maturity of 12 varieties as a result of April 15, May 15 and June 15 plantings over a seven-year period at Lubbock, Texas. Vinall and Reed (8) showed that Dwarf Hegari was seven inches shorter in the late planting, while the average height for the 12 varieties in their test was eight inches taller in the late planting. Bartel and Martin (1) obtained a substantial decrease in weight per stalk and seed weight per head as a result of later plantings at Tucson, Arizona.

PROCEDURE

Two open-pollinated varieties, Combine Sagrain and Early Hegari, and one hybrid, Regional Sorghum 610 (RS 610), were planted at approximately three-week intervals at Gainesville, Fla., in 1958, 1959 and 1960. The first planting date was April 7 in 1958, March 13 in 1959 and March 22 in 1960. Each experiment was laid out as a split-plot design with three replications in 1958 and six replications in 1959 and 1960. Planting dates and varieties were the whole and subplots respectively. The sub-plot size was four rows ten feet long and 38 inches apart in 1958 and 1959 and three rows 16 feet long in 1960.

The soil was plowed in early spring and cultivated as necessary to control weeds prior to seeding at each date. A broadcast application of 500 pounds per acre of 4-10-20 fertilizer preceded each planting in 1958 and 1959, and a similar application of an 8-8-8 analysis was used in 1960. One sidedressing of 33 pounds per acre of nitrogen was used on each date three weeks after planting in each of the years. The seed was treated with a fungicide and drilled with a Planet Jr. planter at somewhat above the standard planting rate, and when necessary the plots were irrigated after planting to insure moisture for germination. Comparable stands were obtained by thinning in the seedling stage to one plant every two or three inches of row or approximately 66,000 plants per acre. Toxaphene and melathion were used for insect control, and a bird repellent was used to

prevent bird damage. However, diseases and birds were not serious in the 1958 and 1959 experiments, and insect control did not become a problem until after the third planting date in each of the three years.

The number of days from planting to heading was determined for each plot during the three-year period. After reaching physiological maturity, the heads were hand-harvested from eight-foot sections from the two center rows of the four-row plots and from a twelve-foot section of the center row from the three-row plots. The heads were artificially dried to five percent moisture and threshed with a plot thresher. The grain yields are presented in bushels of 50 pounds.

The analysis of variance for yield, maturity, and height data was calculated for each individual year. For an analysis of variance of the combined years' experiments, the data from one most nearly comparable early (April), medium (May), and late (June) planting date of each year was selected.

RESULTS AND DISCUSSION

Temperature and moisture data collected at the Agronomy farm for the months of April through July for the three-year period (1958-1960) are given in Table 1. Average temperatures for the three-year period were approximately normal. Of the individual years, the 1960 season was somewhat more favorable by having slightly higher temperatures in the early spring than in 1958 or 1959 and lower temperatures during May and June. The 1960 season was favored in terms of rainfall followed by 1958. The total rainfall was above normal for each of the years but the distribution not uniform.

TABLE 1.—CLIMATOLOGICAL DATA FOR THE GROWING SEASON (APRIL THROUGH JULY) 1958 THROUGH 1960 AT GAINESVILLE, FLA., WITH DEPARTURES FROM NORMAL BASED ON A 51-YEAR AVERAGE.[1]

	Year	Month				Season Average
		April	May	June	July	
Average Temperature (°F.)	1958	69.6 + 0.2	74.8 — 0.7	80.5 + 0.7	81.8 + 1.0	76.7 + 0.3
	1959	69.4 0.0	77.3 + 1.8	79.7 — 0.1	80.8 0.0	76.8 + 0.4
	1960	70.2 + 0.8	73.2 — 2.3	78.2 — 1.6	82.2 + 1.4	76.0 — 0.4
Total Rainfall (Inches)	1958	5.68 + 2.72	5.54 + 2.33	4.91 — 1.80	7.41 — 0.03	5.89 + 0.81
	1959	4.12 + 1.16	9.25 + 6.04	4.44 — 2.27	4.00 — 3.44	5.45 + 0.37
	1960	2.73 — 0.23	1.20 — 2.01	12.80 + 6.09	9.40 + 1.96	6.53 + 1.45

[1]Data from U. S. Weather Bureau, Monthly Summaries of Florida Climatological Data.

TABLE 2.—INFLUENCE OF PLANTING DATE ON THE MEAN YIELD (BUSHELS PER ACRE DRY GRAIN) OF THREE GRAIN SORGHUM VARIETIES AT GAINESVILLE, FLA. IN 1958.

Variety	Planting Date					Mean
	April 7	May 9	May 27	June 16	June 30	
Early Hegari	37.6	16.4	9.4	20.5	7.4	18.3
Combine Sagrain	39.8	12.8	8.3	5.6	3.2	13.9
RS 610	54.9	36.8	28.8	11.5	16.1	29.6
Mean	44.1	22.0	15.5	12.5	8.9	20.6

LSD's 1% level Between date means = 19.5 bushels
Between variety means = 10.0 bushels

GRAIN YIELD

The influence of planting date and variety on the mean yield of grain in 1958, 1959 and 1960 is shown in Tables 2, 3, and 4, respectively. Planting date had a significant and similar effect on yield each year with early April plantings giving the higher yields. The April yields of 44 and 37 bushels per acre in 1958 and 1959, respectively, were significantly higher than those of any other date, and in 1960, the average yield of 75 bushels for the April planting was significantly higher than all but the 70-bushel average for the March planting. These results are similar to those obtained by Karper *et al.* (4) at Beeville, Texas, a location geographically similar to Gainesville, Fla.

In 1959 and 1960, years when the first plantings were made in March, the varieties did not respond similarly to each planting date. As shown in Tables 3 and 4, Early Hegari produced significantly less grain when planted in March than when planted in April, while Combine Sagrain and RS 610 produced equally as well at either date. Early Hegari is apparently more sensitive to the lower temperatures of early spring than the other varieties, as yield was significantly less in the March plantings as compared with the early April plantings.

A sharp decline in yield occurred following the April plantings in each

TABLE 3.—INFLUENCE OF PLANTING DATE ON THE MEAN YIELD (BUSHELS PER ACRE DRY GRAIN) OF THREE GRAIN SORGHUM VARIETIES AT GAINESVILLE, FLA. IN 1959.

Variety	Planting Date					Mean
	March 13	April 3	April 23	May 14	June 5	
Early Hegari	19.3	36.2	29.7	1.2	2.0	17.7
Combine Sagrain	19.7	23.2	3.3	1.3	0.8	9.7
RS 610	48.3	52.8	39.2	4.4	7.8	30.5
Mean	29.1	37.4	24.1	2.3	3.5	19.3

LSD's 1% level Between variety means within or between dates = 7.6 bushels
Between over-all date means = 7.8 bushels
Between over-all variety means = 3.4 bushels

TABLE 4.—INFLUENCE OF PLANTING DATE ON THE MEAN YIELD (BUSHELS PER ACRE DRY GRAIN) OF THREE GRAIN SORGHUM VARIETIES AT GAINESVILLE, FLA. IN 1960.

Variety	Planting Date					Mean
	March 22	April 12	May 3	May 27	June 14	
Early Hegari	59.4	75.4	49.3	16.5	22.8	44.7
Combine Sagrain	74.6	72.2	46.1	22.5	7.7	44.6
RS 610	75.9	78.8	38.0	29.5	19.4	48.3
Mean	70.0	75.5	44.4	22.8	16.6	45.8

LSD's 1% level Between variety means within or between dates = 12.7 bushels
Between over-all date means = 7.1 bushels

of the three years. In these later plantings, much of the seed did not develop, and it is not certain that the flowers were fertilized. Stephens and Quinby (7) showed that sorghums bloom mostly at night or during the early morning hours which means that high temperatures during the pollination period are not likely to be the problem. It takes an average of seven days for all the flowers in a sorghum panicle to bloom or as many as 15 days for late-planted sorghum (7), which gives insects, such as the sorghum midge which are present in greatest numbers during midsummer, an ample opportunity to deposit their eggs in the flowers. Although insecticides were used regularly, some mites were found on the heads and may have been partially responsible. Diseases did not appear sufficiently severe to reduce yields to this extent.

It is shown in Tables 5 and 6 that, next to date of planting, years had the most pronounced effect on grain yield. The year 1960 produced significantly more grain than the year 1958, and in turn, 1958 yields were significantly higher than in 1959. The year 1960, as pointed out previously, was more favorable in temperature and moisture relationships. Also, the 1960 crop received an additional 20 pounds of nitrogen per acre due to the higher analysis fertilizer broadcast at planting. Although the varieties responded similarly to the growing conditions characterizing each year, as revealed by the non-significant year x variety interaction (Table 6), the varieties did not respond the same to the various planting dates as noted by the significant date of planting x variety interaction. The date of planting x year interaction was also significant meaning that the response to the various planting dates was not the same each year. In Table 5, for example, the medium (May 3) planting date in 1960 produced 44.4 bushels of grain which is equally as much as the early (April 7 and April 3) plantings in 1958 and 1959, indicating that for maximum yields it is possible to plant later in some years than in others.

Days to Heading

The influence of planting date on the number of days from planting to heading for the years 1958, 1959 and 1960 is given in Tables 7, 8 and 9 respectively. Highly significant date of planting x variety interactions were obtained each year and also for the combined years as shown in Tables 6 and 10. Early Hegari, in the March and early April plantings, required an average of ten days less than RS 610 and 26 days less than Combine Sagrain from planting to heading, but when planted in June,

TABLE 5.—EFFECT OF DATE OF PLANTING, YEARS, AND VARIETY ON THE MEAN YIELD (BUSHELS PER ACRE DRY GRAIN) OF SORGHUM.

Year or Variety		Date of Planting[1] Early	Medium	Late	Mean
Year	1958	44.1	22.0	12.5	26.2
	1959	37.4	2.3	3.5	14.4
	1960	75.5	44.4	16.6	45.5
Variety	Early Hegari	53.5	19.0	12.7	28.4
	Combine Sagrain	46.1	21.5	4.5	24.0
	RS 610	62.3	28.8	14.5	35.2
	Mean	54.0	23.1	10.6	29.2

[1]*Early* planting was April 7, 3 and 12; *Medium*, May 9, 14 and 3; and *Late*, June 16, 5 and 14 for the years 1958, 1959 and 1960, respectively.

LSD's 1% level

Between date of planting means = 3.7 bushels
Between year means = 3.7 bushels
Between date of planting means within or between years = 6.4 bushels
Between variety means = 3.9 bushels
Between date of planting means within or between varieties = 6.8 bushels

Early Tegari required an average of eight more days to head than RS 610 and one more day to head than Combine Sagrain. The fact that Early Hegari required more days to head and mature when planted late than when planted early indicates that more than low temperatures, as suggested by others (4, 5), affect the maturity of sorghums. Early Hegari appears to be not only more sensitive to low temperatures but also to photoperiod. Vinall and Reed (8) concluded, on the basis of their tests, that late planting hastened maturity, such as was the case with Combine

TABLE 6. MEANS SQUARES FOR YIELD, DAYS TO HEADING AND HEIGHT OF GRAIN SORGHUM IN DATE OF PLANTING STUDIES AT GAINESVILLE, FLA., 1958 TO 1960.

Source of Variance		DF	Mean Squares Yield Bu. /A.	Days to Heading	Height (Inches)
Years		2	13,214.40 **	1,785.49 **	2,219.69 **
Date of Planting		2	22,447.99 **	29.54 **	73.65 *
Dates x Years		4	1,324.40 **	204.08 **	161.94 **
Reps within Years-12 df) Dates x Reps-24 df)	Error "a"	36	40.78 NS	4.54 **	19.95 **
Varieties		2	1,423.67 **	1,536.28 **	24.32 *
Years x Varieties		4	68.42 NS	42.58 **	50.66 **
Dates x Varieties		4	187.19 **	283.23 **	10.68 NS
Dates x Varieties x Years		8	238.87 **	154.70 **	16.37 *
Var. x Reps w /Years-24 df) Var. x Reps x Dates-48 df)	Error "b"	72	49.64	1.32	7.03

* Significant at 5% level.
** Significant at 1% level.
NS Not significant at 5% level.

Sagrain and RS 610 in these tests. However, one variety out of the 12 included in their tests, Dwarf Hegari, required four days longer to mature when planted late than when planted early, while the other varieties matured in an average of 20 days less time when the planting was delayed 55 days. In these experiments, in general, with Combine Sagrain and RS 610, the days from planting to heading decreased progressively with delayed planting; whereas, with Early Hegari, the number of days from planting to heading increased progressively with delayed planting. This trend was without exception for plantings made through mid-May.

When early (April 3-12), medium (May 3-14), and late (June 5-16) planting dates for the three-year period are combined (Table 10), significant effects on the number of days from planting to heading were obtained. The greatest number of days from planting to heading were recorded in 1959 and the fewest in 1960. The mean difference between medium and late plantings was significant, although small. The interactions, date of planting x variety and date of planting x year, were significant. The significance of the date of planting x variety interaction is due primarily to the differential response obtained between Combine Sagrain and Early Hegari. Combine Sagrain required nine days less to complete its vegetative development when planted late than when planted early; whereas, Early Hegari required six days more. The number of days from planting to heading for RS 610 was not significantly affected by these planting dates.

TABLE 7.—INFLUENCE OF PLANTING DATE ON MEAN NUMBER OF DAYS FROM PLANTING TO HEADING OF THREE GRAIN SORGHUM VARIETIES AT GAINESVILLE, FLA. IN 1958.

	Planting Date						
Variety	April 7	May 9	May 27	June 16	June 30	July 15	Mean
Early Hegari	61	64	68	75	68	80	69
Combine Sagrain	75	67	65	72	65	63	68
RS 610	64	55	58	62	61	55	59
Mean	67	62	63	70	65	66	65

LSD's 1% level Between variety means within or between dates = 2.1 days
Between over-all date means = 1.6 days
Between over-all variety means = 0.8 days

TABLE 8.—INFLUENCE OF PLANTING DATE ON MEAN NUMBER OF DAYS FROM PLANTING TO HEADING OF THREE GRAIN SORGHUM VARIETIES AT GAINESVILLE, FLA. IN 1959.

	Planting Date					
Variety	March 13	April 3	April 23	May 14	June 5	Mean
Early Hegari	56	61	66	80	72	68
Combine Sagrain	102	84	82	80	70	85
RS 610	75	71	64	68	62	69
Mean	78	72	71	76	68	73

LSD's 1% level Between variety means within or between dates = 2.1 days
Between over-all date means = 1.7 days
Between over-all variety means = 1.0 days

TABLE 9.—INFLUENCE OF PLANTING DATE ON MEAN NUMBER OF DAYS FROM PLANTING TO HEADING OF THREE GRAIN SORGHUM VARIETIES AT GAINESVILLE, FLA. IN 1960.

Variety	Planting Date						Mean
	March 22	April 12	May 3	May 27	June 14	July 6	
Early Hegari	63	49	58	59	62	59	58
Combine Sagrain	87	72	67	66	65	64	70
RS 610	71	58	57	56	56	53	59
Mean	74	60	61	60	61	59	62

LSD's 1% level Between variety means within or between dates = 1.6 days
Between over-all date means = 1.3 days
Between over-all variety means = 0.7 days

The influence of daylength (photoperiod) on the mean number of days from planting to heading for grain sorghum varieties planted during April, May, June and July is shown in Figure 1. Early Hegari headed most rapidly when daylengths were becoming increasingly longer and was least physiologically receptive when daylengths were shortening. In contrast, Combine Sagrain was slower to head when daylengths were becoming greater and headed most rapidly when daylengths were becoming shorter. RS 610 was rather unaffected by the lengthening photoperiod but heading was hastened by the shortening daylengths. Hence, the statement, that the earlier the variety the later it can be sown, should be qualified as it is shown that not all sorghum varieties respond similarly to low temperatures or photoperiod. This comparatively wide variation among sorghum varieties in response to date of planting should increase their potential usefulness in Florida where there is often need for a crop that can be

TABLE 10.—EFFECT OF DATE OF PLANTING, YEARS, AND VARIETY ON THE MEAN NUMBER OF DAYS FROM PLANTING TO HEADING FOR GRAIN SORGHUM AT GAINESVILLE, FLA.

Year or Variety		Date of Planting[1]			Mean
		Early	Medium	Late	
Year	1958	67	62	70	66
	1959	72	76	68	72
	1960	60	61	61	60
Variety	Early Hegari	60	68	66	65
	Combine Sagrain	77	72	68	73
	RS 610	61	61	62	61
	Mean	66	67	65	66

[1]*Early* planting was April 7, 3 and 12; *Medium*, May 9, 14 and 3; and *Late*, June 16, 5 and 14 for the years 1958, 1959 and 1960, respectively.

LSD's 1% level

Between date of planting means = 1.2 days
Between year means = 1.2 days
Between date of planting means within or between years = 2.1 days
Between variety means = 0.6 days
Between date of planting means within or between varieties = 1.1 days

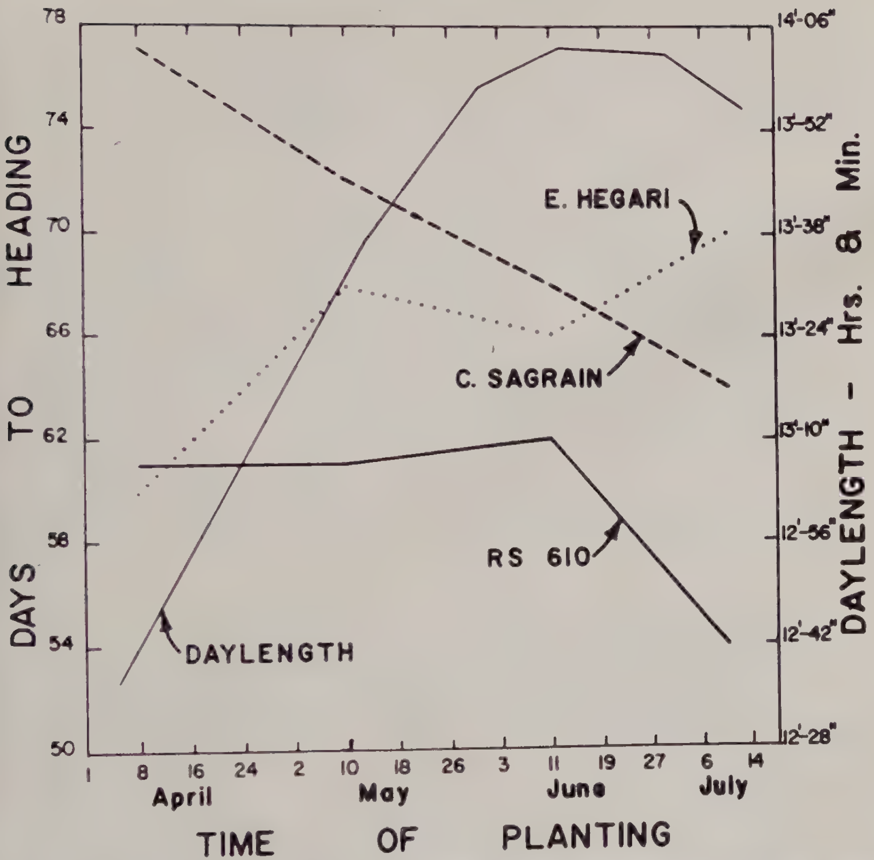

Figure 1.—Influence of daylength on the mean number of days from planting to heading for three varieties of grain sorghum at Gainesville, Fla., for the years 1958, 1959 and 1960. (July data from 1958 and 1960 only—Daylength data taken from the Smithsonian Meteorological Tables, 6th Rev. Edition, 1951.)

planted at a time that will not greatly interfere with the growing and harvesting of a winter crop such as oats or rye.

Height

The effect of date of planting, year, and variety on plant height is summarized in Table II and the mean squares given in Table 6. Planting date had much less effect on the height of plants than on the maturity and yield. Years were, by far, the largest contributor to the variance in plant height as would be expected in view of the more favorable growing season and increased nitrogen in 1960. The mean plant height in 1960 was nine inches above that in 1958 and 13 inches above the 1959 mean plant height. The over-all mean difference between the three varieties and between the three planting dates, although statistically significant, was only two inches in each case. Combine Sagrain averaged two inches taller than Earli Hegari, and the late-planted sorghum was slightly taller than early planted sorghum, which is in accord with findings of others (2,

TABLE 11.—EFFECT OF DATE OF PLANTING, YEARS, AND VARIETY ON THE MEAN HEIGHT (IN INCHES) OF GRAIN SORGHUM AT GAINESVILLE, FLA.

Year or Variety		Date of Planting[1] Early	Medium	Late	Mean
Year	1958	41	49	50	47
	1959	45	41	44	43
	1960	53	58	57	56
Variety	Early Hegari	47	48	50	48
	Combine Sagrain	49	51	50	50
	RS 610	47	49	50	49
	Mean	48	49	50	49

[1]*Early* planting was April 7, 3 and 12; *Medium*, May 9, 14 and 3; and *Late*, June 16, 5 and 14 for the years 1958, 1959 and 1960, respectively.

LSD's

Between date of planting means (5% level) = 1.9 inches
Between year means (1% level) = 2.6 inches
Between date of planting means within or between years (1% level) = 4.4 inches
Between variety means (5% level) = 1.1 inches

5, 8). Considerably more variation was accounted for in the date of planting x year and year x variety interactions. In 1959, the mean plant heights for the three dates were not statistically significant; whereas, statistically significant differences were obtained in mean plant heights between the three planting dates in 1958 and in 1960. The influence of date of planting on the height of the plants of the different varieties was not statistically significant.

SUMMARY

Results are reported of field experiments conducted with three grain sorghum varieties planted at different dates over a three-year period at Gainesville, Fla. The effect of planting date on yield, number of days from planting to heading, and plant height were studied.

The grain sorghum varieties in this test responded quite differently to date of planting in terms of effect on yield and maturity. Plant height was affected by date of planting but to a much lesser degree. Early Hegari, considered to be an early variety, was more sensitive to the lower, early spring temperatures than Combine Sagrain or RS 610, varieties generally classified as medium in maturity, and yielded significantly less when planted in March than when planted in April. Combine Sagrain and RS 610 produced equally as well at either the March or April planting dates. All three varieties yielded significantly more from early April plantings than plantings in May or June.

Years differed in their effect on yield, maturity, and height of the varieties; however, the varieties did not respond to the various planting dates the same each year.

Highly significant date of planting x variety interactions were obtained in regard to the number of days from planting to heading which indicates that it should be possible to develop sorghum varieties that

would be adapted to either early or late plantings. Early Hegari, when planted in March or early April, required an average of ten days less from planting to heading than did RS 610 and 26 days less than Combine Sagrain, but when planted in June, Early Hegari required an average of eight more days than RS 610 and one more day to head than Combine Sagrain.

LITERATURE CITED

1. Bartel, A. T. and J. H. Martin. The growth curve of sorghum. J. Agr. Res. 57: 843-849. 1938.
2. Cushing, R. L., T. A. Kiesselbach and O. J. Webster. Sorghum production in Nebraska. Nebraska Agr. Exp. Sta. Bul. 329. 1940.
3. Garner, W. W. and H. A. Allard. Further studies in photoperiodism, the response of the plant to relative length of day and night. J. Agr. Res. 23: 871-920. 1923.
4. Karper, R. E., J. R. Quinby, D. L. Jones and R. E. Dickson. Grain sorghum date-of-planting and spacing experiments. Texas Agr. Exp. Sta. Bul. 424. 1931.
5. Martin, J. H. and J. B. Sieglinger. Spacing and date-of-seeding experiments with grain sorghums. U.S.D.A. Tech. Bul. 131. 1929.
6. Ross, W. M. and O. J. Webster. Culture and utilization of grain sorghum. U.S.D.A. Inf. Bul. 218. 1960.
7. Stephens, J. C. and J. R. Quinby. Anthesis, pollination, and fertilization in sorghum. J. Agr. Res. 49: 123-136. 1934.
8. Vinall, H. N. and H. R. Reed. Effect of temperature and other meteorological factors on the growth of sorghums. J. Agr. Res. 12: 133-148. 1918.

A Comparison of Oat And Rye Pastures For Fattening Long-Yearling Steers In South-Central Florida[1]

J. E. McCALEB, F. M. PEACOCK, E. M. HODGES AND W. G. KIRK[2]

Annually seeded winter non-legume forages have received considerable attention in recent years as a means of providing feed for cattle grazing in Southeastern United States. Stockmen in central, northern and western Florida have used oats and rye for grain, seed production, hay and livestock grazing for many years. Morey *et al.*[3] state that oats are grown as a winter pasture and grain crop principally in north Florida and that a high percentage of this acreage is grazed at least once from November through March with less than one fourth being harvested for grain. While grazing of temporary winter pastures is an accepted program in north Florida and other areas of the Southeast, little information is available pertaining to the performance of beef cattle grazing small grains on the mineral soils of south-central Florida.

A preliminary study was made in the winter 1955-56 to determine productivity and climatic adaptability of 5 varieties of oats and 2 of rye at the Range Cattle Station. Each variety was planted October 18, 1955, in replicated plots and harvested at 7, 14, 21 and 28-day intervals from November 22 to February 27. The results of this trial are given in Table 1.

Based on the yield data shown in Table 1 and observations of growth

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[3]Morey, Darrell D., W. H. Chapman and R. W. Earhart. Growing oats in Florida. Fla. Agr. Exp. Sta. Bul. 523, August 1953.

habits of individual varieties, grazing trials were started in fall 1956 using oats and rye. The objectives of this study were to compare oats with rye in relation to: (1) grazing value for growing and fattening beef cattle; (2) yield of forage and pounds of TDN produced per acre; (3) seasonal distribution of forage and feed quality; (4) evaluation of the feasibility of temporary pastures as an aid to renovation of improved pastures; (5) management and fertilization procedures; (6) cost of production. Results obtained relative to the first objective will be discussed in detail.

TABLE 1.—TOTAL YIELD IN TONS OF GREEN FORAGE PER ACRE OF OAT AND RYE VARIETIES FOR 1955-56.

Variety		Cutting Intervals in Weeks[1] 1	2	3	4
Oats:	Floriland	6.2	7.4	10.2	11.3
	Alamo	4.5	6.8	9.5	12.8
	Southland	6.7	6.3	9.7	9.1
	Seminole	5.6	7.0	8.8	10.1
	Sunland	3.6	5.8	6.7	10.6
Rye:	Gator	6.7	8.2	8.7	11.1
	Florida Black	5.2	7.5	8.4	10.9

[1]Clipping height 2 inches. Grain production not determined.

METHOD OF PROCEDURE

The soil in the areas used was comparable in drainage and classified as Immokalee fine sand. The pH ranged from 5.8 to 6.6 and minor elements were in ample supply. Yearly rainfall for September through April averaged 23.70 inches from 1942 to 1956 and 30.96 inches from 1956 to 1960, an increase of 30.6% for the trial years. Average monthly maximum and minimum temperatures for the 1956 to 1960 period fluctuated less than 2° F. from the 1942 to 1956 normal. All fields had been used in other grazing trials and had become so severely infested with smutgrass (*Sporobolus poiretii*), common bermudagrass (*Cynodon dactylon*) and carpetgrass (*Axonopus affinis*) that productivity was decreased to the extent that renovation was required.

Trials to determine the value of oat and rye temporary winter pastures for fattening long-yearling steers were started in the fall of 1956 and continued through 1956. Each grain was planted yearly in 3 fields, each 2.5 acres in size to permit rotational grazing. The same fields were planted in the fall of 1956 and 1957 and different areas were used in each of the following years. Floriland oats were planted in each of the 4 trials. Abruzzi rye was seeded in 1956, Florida Black rye in 1957 and Gator rye, which became commercially available in 1957, was used in 1958 and 1959. Seed were distributed with a fertilizer spreader, covered with a disk and compacted twice with a culti-packer. Plantings were made in the first week of October in all years; however, excessive rainfall in late October, 1959 necessitated replanting of all rye and 2 oat fields on November 10. Fertilizer was applied at the rate of 400-500 pounds of 9-6-6 or similar mixture per acre at planting time. Additional treatments of 30 to 50 pounds of N per acre as ammounium nitrate were made at 4 to 6-week intervals when

TABLE 2.—COMPARISON OF OATS AND RYE FOR FATTENING LONG-YEARLING STEERS.

Year	1956-57		1957-58		1958-59		1959-60		Four-year Average	
Variety	Floriland Oats	Abruzzi Rye	Floriland Oats	Fla. Black Rye	Floriland Oats	Gator Rye	Floriland Oats	Gator Rye	Oats	Rye
Bu. seed /A	2	2	4	2	3	1.5	4	2	--------	--------
Grazing period										
From	12-6	12-6	12-3	12-3	11-21	11-21	12-18	12-18		
To	4-16	4-16	3-28	1-21	3-17	3-17	4-13	4-13	--------	--------
No. steers continuously on pasture	7	5	7	4	7	5	8	7	--------	--------
Length grazing period, days	131	131	115	49	113	113	116	117	119	103
Total gain /A	250	135	119	12	254	166	286	163	227	119
Av. weights:										
Initial	890	926	841	868	659	648	686	700	766	773
Final	1126	1128	969	886	874	855	902	881	965	934
Gain	236	202	128	18	215	207	216	181	199	161
Av. daily gain	1.80	1.54	1.11	0.37	1.90	1.83	1.86	1.55	1.66	1.39

required to maintain vigorous growth and forage quality. The fertilizer material was applied in equal amounts to each variety for any given year. Grazing began in early December with 5 to 7 long-yearling steers of comparable grade and breeding, with the put-and-take method of grazing used to maintain the desired balance between forage supply and cattle. Herbage was 6 to 12 inches in height at the beginning of the grazing period and averaged 4 inches or more when steers were rotated between pastures. Salt. bonemeal and a modified salt sick mineral supplement were available to the steers in each pasture throughout the trials.

EXPERIMENTAL RESULTS AND DISCUSSION

Grazing of oat and rye pastures was begun on December 6, December 3, December 24 and December 18 during the successive years, beginning in December, 1956. Intervals between planting and initiation of grazing ranged from 58 to 72 days. Seeding date appeared to be the principal factor determining the time pastures were ready. The length of grazing season ranged from 113 to 131 days for oats and 49 to 131 for rye.

The results of 4 grazing trials comparing oats and rye for fattening steers are shown in Table 2.

The data presented in Table 2 show that Floriland oats have consistently given higher daily gains, per-acre gains and more days of grazing than any of the rye varieties. Gator rye was more productive than Abruzzi or Florida Black. Carrying capacity for continuous grazing was 1.03 acres per steer for oats and 1.42 acres for rye.

Rainfall for the months September through April, 1956-60 averaged 30.6 percent higher than the corresponding period from 1942-55. Abnormally heavy rainfall and lower than average temperatures in December and January, 1957-58 resulted in decreased gain for oats, although the 115-day grazing period was only slightly below average. Rye was so severely damaged in 1957-58 that grazing had to be discontinued after 49 days.

Tobacco Plant Production As Affected By Plantbed Management Practices[1]

E. B. WHITTY and FRED CLARK[2]

The purpose of this paper is to report some efforts to improve tobacco plant production through plantbed management practices.

Vigorous transplants are the foundation of profitable flue-cured tobacco production. Most agronomists recommend that farmers have their own tobacco beds for the production of transplants. This practice assures the farmer, not only of having transplants when they are needed, but also of being more certain of their vigor.

In Florida, tobacco plantbeds are usually sown in December or January. Plants may then reach transplanting size from late February to late April,

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depending upon the weather. The conventional cheesecloth cover is far from adequate for maintaining an environment optimum for plant growth; therefore, when sown beds are covered with cheesecloth, there is no way of accurately predicting when the seedlings will be ready to transplant. Since weather conditions and seedling growth vary widely, the time of transplanting also varies. For this reason, there have been few, if any, experimental determinations of the optimum dates for transplanting. The standard recommendation as to the time to transplant is, "when the plants are ready."

Other problems in plant production include the lack of seedling vigor due to inadequate nutrition, and the low percentage of seedlings produced relative to the number of seed sown. Tobacco beds are usually sown at the rate of one-half to one ounce of seed per 100 square yards. This is from 150,000 to 300,000 seed. About two to three acres, which requires only 15,000 to 35,000 plants, are set from each 100 square yard bed. Thus, for each seedling that is transplanted, there are about nine seed that never produce a transplantable seedling.

It is necessary that the soil in the plantbed be kept in a state of high fertility for rapid and vigorous growth of young tobacco plants. This is due to the small amount of food reserves stored in the seed, the high nutrient requirements of the plant, and the dense stand of plants in the bed. Normally about one and one-half to two pounds of a complete fertilizer are applied to each square yard of bed area. This amount of fertilizer should be sufficient, but due to leaching losses of nitrogen, plants may show nitrogen deficiencies before they are ready to transplant.

REVIEW OF LITERATURE

The effects of temperature on plant growth are well known. Favorable temperatures are especially important for plants of tropical or sub-tropical origin, such as tobacco. The importance of favorable temperatures in the production of tobacco plants in Florida has been thoroughly confirmed by Pettis (17), Dean (5), and Saunders (19).

Powell (19) found 20° C. to be more favorable than either 10° C. or 30° C. for the germination of tobacco seed. Toole *et al.* (23) also found that a constant temperature in excess of 30° C. was unfavorable for germination of tobacco seed. They found that germination was improved by a diurnal alteration of temperature.

Went (25) found that the night temperature is the most critical environmental factor in controlling the growth rate of tobacco. He stated that the optimum night temperatures shift from 30° C. for very young plants to lower levels as the plants become older.

Steinberg (20, 21) found that the temperature used to grow tobacco seedlings affected their subsequent development in the field. Premature blossoming and fewer leaves resulted from low plantbed temperatures. Muraoka and Ohori (16) compared plants grown at low (10°-20° C.) and high (20°-30° C.) plantbed temperatures. They observed that the vegetative growth (in the field) of plants from the low temperature plantbed was inferior to those from the warmer bed, but the former plants were more hardy and could better withstand low temperatures at transplanting. Steinberg (21) advised that premature blossoming of tobacco could be prevented by the later sowing of seed and the use of higher temperatures during the seedling stage. Saunders (19) found that higher yields of

tobacco are obtained if seedlings are grown under the conditions set forth by Steinberg.

Methods of increasing plantbed temperatures have been varied and numerous. In the pioneer days of this country, Garner (7) stated tobacco plantbeds were covered with brush. In 1887, Professor Moodie (15), of the Florida Agricultural Experiment Station in Lake City, recommended that tobacco plantbeds be covered in a "shingle fashion," with straight leafless brush.

Tilley (22) stated that cloth was first used as a tobacco plantbed cover in 1877, and soon caused a mild revolution in plant production. Garner (7) stated that cloth covers with about 24 threads to the inch are satisfactory, since lighter weaves offer little protection and heavier weaves exclude to much light.

Henderson *et al.* (8) found that tobacco plants made excellent growth under flexible glass-substitute covers and were surprisingly hard and tough. Saunders (19) used several different plantbed covers, and found that fiberglass excluded too much light, and saran did not offer enough protection for good plant growth.

Pettis (17) and Dean (4) increased seedling growth with electric soil heating cables, but found it difficult to keep the beds moist enough to prevent loss of plants. Furuya and Sasaki (6) had more speedy seedling growth, but the costs were much higher with electric heated beds than with other type beds.

In 1952, Clark and Volk (3) stated that plastic film had promise as tobacco plantbed covers. Kubota *et al.* (10) found that a tunnel-type tobacco plantbed cover of plastic film resulted in better growth of the seedlings, easier management, and lower cost than any other type they tried. Saunders (19) found that beds covered with vinyl and polyethylene plastic films produced tobacco transplants of optimum transplanting size 30 days sooner than beds with conventional cheesecloth covers. These plants were produced in less time because of faster germination, higher temperatures, and more frost protection.

Saunders (19) further concluded that plants could be produced at a more optimum transplanting time with plastic film. Another feature of the plastic covers used by Saunders was the prevention of leaching of plant nutrients from the soil by heavy rains.

Tobacco plant production is considerably influenced by the form of nitrogen used in the plantbed. When used alone, McCants and Woltz (12) found the organic sources of nitrogen to be unsatisfactory. Although the ammonia toxicity which occurs in field tobacco has not been reported in plantbeds, Dean *et al.* (5) showed that the tobacco seedling made less growth with ammonium than with nitrate nitrogen. They found that changing to ammonium nitrogen after growing seedlings on nitrate nitrogen for 40 days caused a darkening of the leaves as well as slowed rates of growth. These plants also had a lower carbohydrate level at transplanting and a slower rate of root regeneration after transplanting than those receiving continuous nitrate nitrogen.

Beaumont (1) found the toxicity from ammonium salts to be a slowly accumulative effect. He believed that the tobacco plant absorbed ammonium nitrogen faster than nitrates, but could assimilate only very little ammonium nitrogen. He further stated that this assimilation may have been in the early stages of growth, since young plants grew faster when part of the nitrogen was in the ammonium form.

Although the nitrate ion is the most useful form of nitrogen for tobacco nutrition, Garner (7) stated that it is of comparatively little value for tobacco beds because of the ease with which it is leached from the top layer of soil. Clark and Volk (3) recommended top-dressing tobacco plantbeds with sodium nitrate, if it became necessary for maintenance of the supply of available nitrogen.

The transformation of ammonium to nitrate nitrogen is by nitrification, a process greatly affected by the temperature. Waksman (24) stated that nitrate formation was noticeable at 5° C., became prominent at 12° C. and reached a maximum at 37° C. Higher temperatures, such as 45° C. exerted an injurious effect, and at 55° C. the process came to a standstill. McCants *et al.* (14) found that soil fumigants reduced nitrification. On the basis of this, McCants and Woltz (13) recommended that the fertilizer applied to plantbeds fumigated with methyl bromide contain at least 25% of the nitrogen in the nitrate form.

Carr (2) presented results of studies on different sources of nitrogen in Georgia tobacco plantbeds. Woltz (26) presented results of similar experiments he conducted in North Carolina and of other studies in South Carolina. All investigators found that sodium nitrate was the poorest of all sources of nitrogen used in tobacco plantbeds. South Carolina results showed no appreciable differences between the remaining treatments, which included two rates of a mixture of equal portions of all materials that had been used individually. Georgia results showed the mixture to be superior. There were no differences between rates of one pound and two pounds of the mixture per square yard. North Carolina experiments were carried out at several locations. Some experiments revealed no differences among treatments, but from all experiments, the author concluded that when beds were fall-treated with Uramon and Cyanamid, urea gave the best results.

Leone and Shive (11) attempted to improve the quality of tomato seedlings by varying nitrogen and phosphorus levels. They found that increased carbohydrate levels improved the rooting ability of tomato plants, a conclusion also reached by Dean *et al.* (5) with tobacco. Both groups of investigators found that the carbohydrate level of the two plants could be increased by using low levels of nitrogen. Leone and Shive (11), after finding the same results with limited phosphorus, concluded that the best tomato seedlings for successful transplanting were produced by a limitation of phosphorus rather than nitrogen.

MATERIALS AND METHODS

Experiments dealing with plantbed covers, seeding dates, varieties, delayed transplanting, sources of nitrogen, rates of nitrogen fertilization, and methods of fertilizer application were conducted in 1959 and 1960. From three experiments in 1959, the program was expanded to six experiments in 1960. Each of these experiments are numbered and will be described later.

The entire study was conducted at the Tobacco Unit of the Florida Agricultural Experiment Station at Gainesville. The laboratory work was conducted in the Soil Testing Laboratory of the Florida Agricultural Extension Service.

The soil type at the Tobacco Unit is Lakeland fine sand. Both temporary and permanent plantbeds were used. The permanent beds were of

either concrete block or poured concrete. The temporary beds had sidewalls of 2 x 4 treated lumber, with necessary supports for the cover. Where plastic covers were used on the permanent beds, A-type frames (6 x 12 or 3 x 6 feet) were covered with plastic film. The beds were irrigated, as necessary, with either a straight water nozzle or perforated plastic hose that remained in the bed. Beds were dusted with 15% Ferbam at necessary intervals for the prevention of blue mold.

Pearlmillet was used as a summer cover crop. In the fall, peanut hay was added to the beds and rye planted for a cover crop. About a week before seeding, the rye was turned, and the beds were fumigated with methyl bromide. Beds not in fertilizer tests were top-dressed with a sodium nitrate solution, as necessary.

Certified seeds of the Hicks and 402 varieties were obtained through commercial outlets. Seeds of the F22-2 and PD 611 varieties were collected the previous year from Station plots.

Experiment 1

The 1959 test consisted of a comparison of plantbed covers, seeding dates, and varieties. A split-split-plot design with four replications was used. Covers, seeding dates, and varieties were the main plots, sub-plots, and sub-sub-plots, respectively. Cheesecloth, polyethylene, vinyl, and polyethylene with a soil heating cable were the main plots. Hicks, 402, and F22-2 varieties were seeded January 2, January 22, and February 11. The electric soil heating cable was set so as to maintain a temperature of 60° F. one inch below the soil surface. Before seeding 6-9-3 fertilizer was applied at the rate of one and one-half pounds per square yard. Individual plots were eight square feet in area, and the seeding rate was slightly more than one ounce per 100 square yards. Beds with plastic covers were ventilated when believed necessary. Temperatures were recorded with a 20-point Honeywell instrument. Copper-constantan-thermocouples were placed three inches above the soil surface, at the soil surface and one inch below the soil surface.

Plant counts were made 25 and 40 days after seeding. Four one-fourth square foot areas in each plot were selected at random for this purpose.

As the seedlings became of transplanting size, they were pulled and counted. The number of days needed to produce transplants was calculated from the day of seeding to the day of the first pulling. At the first pulling, a substantial number of plants were of the required size. The remaining plants were pulled at semi-weekly or weekly intervals, depending on the rate of plant growth. No further pullings were made after the normal period for transplanting had passed. Therefore, the earlier plantings had a longer period during which transplants were produced.

Experiment 2

A second experiment in 1959 was designed to determine the effects of the thickness of plantbed covers on three varieties of tobacco. A split-plot design with three replications was used. Polyethylene in 2 and 3 mil thicknesses (1 mil = 0.001 inch), vinyl in 2 and 4 mil thicknesses, 4 mil vinyl in two layers, and cheesecloth, as a check, were the covers. The varieties were the same as in Experiment 1. The vinyl cover in two layers was constructed by completely covering both the inside and outside of an A-type frame. This gave an air pocket between the layers, which supposedly reduced heat loss from the bed at night.

Plots were two-thirds square yard in area and were seeded at the rate of one ounce per 100 square yards. Each square yard received one and one-half pounds of 6-9-3 fertilizer about a week before seeding. Plant counts were made as in Experiment 1.

Experiment 3

The final 1959 experiment consisted of a comparison of sources of nitrogen in the tobacco plantbed. The 402 variety was used in a randomized block design with four replications. Hoagland's nutrient solution, sodium nitrate, ammonium nitrate, ammonium sulfate, urea, and a mixture of ammonium sulfate and sodium nitrate (equal amounts of nitrogen) were the sources of nitrogen. The Hoagland's nutrient solution was composed of ammonium phosphate, potassium nitrate, calcium nitrate, and magnesium sulfate. It was prepared according to the directions for Solution 2 on page 30 of the bulletin by Hoagland and Arnon (9).

Fertilizers were applied at rates that supplied 0.09 pounds of elemental nitrogen per square yard. All fertilizers, except the Hoagland's solution, were mixed with an 0-9-3 base and incorporated with the top two or three inches of soil before seeding. Five applications of Hoagland's solution were used, with the later applications (during maximum plant growth) being more concentrated and more frequent. It should be pointed out that the Hoagland's solution did not furnish the same amount of P_2O_5 and K_2O as the 0-9-3 base. The bed was sown on January 26 and covered with cheesecloth.

The only data collected from this experiment was a plant count made 40 days after seeding and a count of transplantable seedlings pulled from each plot.

Experiment 4

Another comparison of covers, seeding dates, and varieties was made in 1960 which was similar to Experiment 1. The only changes were the replacement of the polyethylene cover and soil heating cable with Mylar, another plastic film. Beds with cheesecloth covers were sown on December 11, January 6, and January 27, and those with plastic covers were sown on January 6, January 27, and February 17. These seeding dates were chosen to facilitate an experiment with transplanting dates.

Experiment 5

A test similar to Experiment 3 was conducted in 1960. The urea treatment was replaced with a commercial 6-9-3 mix, prepared especially for tobacco plantbeds. Ammonium nitrate, ammonium sulfate, and ammoniated superphosphate were the sources of nitrogen in the 6-9-3, and they were compounded to supply two-thirds of the nitrogen as ammonium and one-third as nitrate. Four varieties—Hicks, 402, F22-2, and PD 611—were sown on January 12, and the bed was covered with cheesecloth. The experiment was in a factorial design with three replications. Transplants were counted as in Experiment 3. Ten plants were selected at random from each plot for dry weight determinations. Pulling the plants naturally caused many of the finer roots to be left in the soil, but information was sought on the transplantable seedling and not on the seedling as it grew in the bed. The diphenylamine test was used for determination of nitrates in soil samples collected on March 4.

Experiment 6

This experiment was identical to Experiment 5, except that the bed was covered with ployethylene film and the seed were sown on January 28.

Experiment 7

This experiment consisted of a comparison of sodium nitrate and Hoagland's solution under cheesecloth cover. Both fertilizers were applied at the rate of 0.06, 0.09, or 0.12 pounds of nitrogen per square yard, in either one, two, four, or eight applications. An 0-9-3 base on all sodium nitrate plots, and the entire rates for the single applications of both fertilizers were applied before seeding. The first applications of fertilizers on the other plots were made after the seed had germinated. Equal applications were continued weekly, bimonthly, or monthly, depending on the required number of applications.

A split-split-plot design was used with fertilizer as the main plot, rates as sub-plots, and number of applications as sub-sub-plots. Three replications were used, and the 402 variety was sown on January 20.

Experiment 8

This experiment was identical to Experiment 7, except that a polyethylene cover was used and the beds were sown on February 3.

Experiment 9

The final experiment reported in this paper was a study of delayed transplanting. Plants were pulled on March 31, and on alternate days thereafter until April 8, when all plants were set in the field. Roots of those plants pulled 2, 4, 6, or 8 days before transplanting were placed in moist peat moss (heeled-in), and an attempt was made to initiate root growth with either Hoagland's solution, Rootone (a root initiating hormone), or plain water (control). These treatments were compared to the plants that were pulled and set the same day (check). The experiment was in a factorial design with four replications.

RESULTS

The results of these experiments are reported in number of transplants; dry weight of plants; nitrate level in the soil following various fertilization treatments; as well as other factors affecting the value of the treatments, such as rainfall, temperature, and light intensity. Results are presented in tables and graphs.

Since some of the experiments are closely related, results are combined for easier comparison.

Experiments 1 and 4

Plant counts, 25 and 40 days after seeding, were made in 1959 (Experiment 1). These results are shown in Table 1, where it can be seen that seed germinated faster, and more seedlings were grown under the plastic covers than under the cheesecloth. Except for low counts under cheesecloth for the February 11 seeding, no general trends in plant population for different seeding dates were noted. The number of plants produced by F22-2 was slightly lower than for Hicks and 402, probably because of the lower quality of F22-2 seed.

TABLE 1.—EFFECT OF PLANTBED COVER, SEEDING DATE, AND VARIETY ON THE NUMBER OF TOBACCO PLANTS PER SQUARE YARD, 25 AND 40 DAYS AFTER SEEDING, 1959 (EXPERIMENT 1). GAINESVILLE, FLA.

		Variety							
		Hicks		402		F22-2		Average	
Cover	Seeding Date	25 Days	40 Days	25 Days	40 Days	25 Days	40 Days	25 Days	40 Days
Cheesecloth	Jan. 2	1926	2358	1485	2574	1512	2430	1638	2457
	Jan. 22	2880	2493	3492	2475	3204	1908	3195	2295
	Feb. 11	1728	1350	1359	1350	1278	1188	1458	1296
Polyethylene with Heating Cable	Jan. 2	3969	2970	3690	2826	3483	2574	3717	2790
	Jan. 22	3852	3474	3753	2700	3168	2250	3591	2493
	Feb. 11	2502	1980	2394	2124	2097	2250	2331	2115
Polyethylene	Jan. 2	3942	3474	3168	3114	2601	2232	3240	2943
	Jan. 22	2898	2709	2556	2142	2394	2034	2619	2295
	Feb. 11	2601	2358	2169	2790	1989	1764	2250	2304
Vinyl	Jan. 2	3636	2790	2502	2493	2772	2205	2970	2493
	Jan. 22	2862	2016	2880	2268	2988	2338	2907	2277
	Feb. 11	3078	2304	2277	2268	2160	2196	2502	2259
Average		2988	2448	2646	2430	2466	2133	2700	2337

Table 2 shows the number of transplants produced in 1959 and 1960. Highly significant differences existed between covers and seeding dates for both years. More transplants were produced in 1959 than in 1960, due to differences in seeding rates and weather conditions. The 1960 seeding rate was one-third less than the 1959 rate. Since so many seed germinated under the plastic film in 1959, causing the plants to be spindly, it was felt that better transplants could be produced with a lower rate of seeding.

Two interesting points may be noted from the data in Table 2. One is that the polyethylene-covered bed produced more transplants than did the other covers in almost every case. This trend was also noted in other experiments; however, it was not always significant.

The number of days from seeding until transplanting was considerably lower with plastic covers than with cheesecloth, as shown in Table 3. No exact measurements (since there are none) were made to determine when the seedlings were ready to transplant, but rather transplantings were made when a sufficient number of plants of optimum size. If more exact measurements had been used, the number of days may have been different, but by not more than five days. For instance, the transplanting from the January 6, 1960 seeding could have been made three or four days earlier, if the weather had been suitable. An occurrence that may have practical significance is the small variation in the number of days needed to produce transplants under plastic covers between years and dates. These results are in good agreement with those of Saunders (19).

Factors affecting the above results would include temperatures under various covers. The temperatures under these covers for the 24-hour period on January 23, 1959, are shown in Figure 1. This day was slightly colder than the average January day. The temperature curve for cheesecloth was almost the same as the outside temperature, and in the early

TABLE 2.—EFFECT OF PLANTBED COVER, SEEDING DATE, AND VARIETY ON THE NUMBER OF TOBACCO TRANSPLANTS PRODUCED PER SQUARE YARD, 1959 AND 1960 (EXPERIMENTS 1 AND 4). GAINESVILLE, FLA.

	1959			1960				1959			1960			Average	
Cover	Jan. 2	Jan. 22	Feb. 11	Dec. 11	Jan. 6	Jan. 27	Feb. 17	Hicks	402	F22-2	Hicks	402	F22-2	1959	1960
Cheesecloth	362	186	17	415	150	55	.....	208	162	195	211	194	215	188	207
Polyethylene	909	656	219		476	353	90	767	522	626	312	316	291	638	306
Vinyl	819	588	231		493	303	80	598	522	518	321	312	243	546	296
Polyethylene w/Heating Cable	857	531	143	......	......	......	.....	602	438	497	....	.	..	512	....
Mylar	.....	.....	......	......	394	228	49	....	....	......	217	248	206	.....	224
Average	737	490	152	415	378	235	73	544	411	459	265	268	239	471	257

TABLE 3.—EFFECT OF PLANTBED COVER AND SEEDING DATE ON THE NUMBER OF DAYS NEEDED TO PRODUCE TOBACCO TRANSPLANTS, 1959 AND 1960 (EXPERIMENTS 1 AND 4). GAINESVILLE, FLA.

	1959		1960	
Cover	Date	Days	Date	Days
Cheesecloth	January 2	88	December 11	98
	January 22	75	January 6	93
	February 11	65	January 27	—
Plastics	January 2	60	January 6	72
	January 22	57	January 27	65
	February 11	55	February 17	58

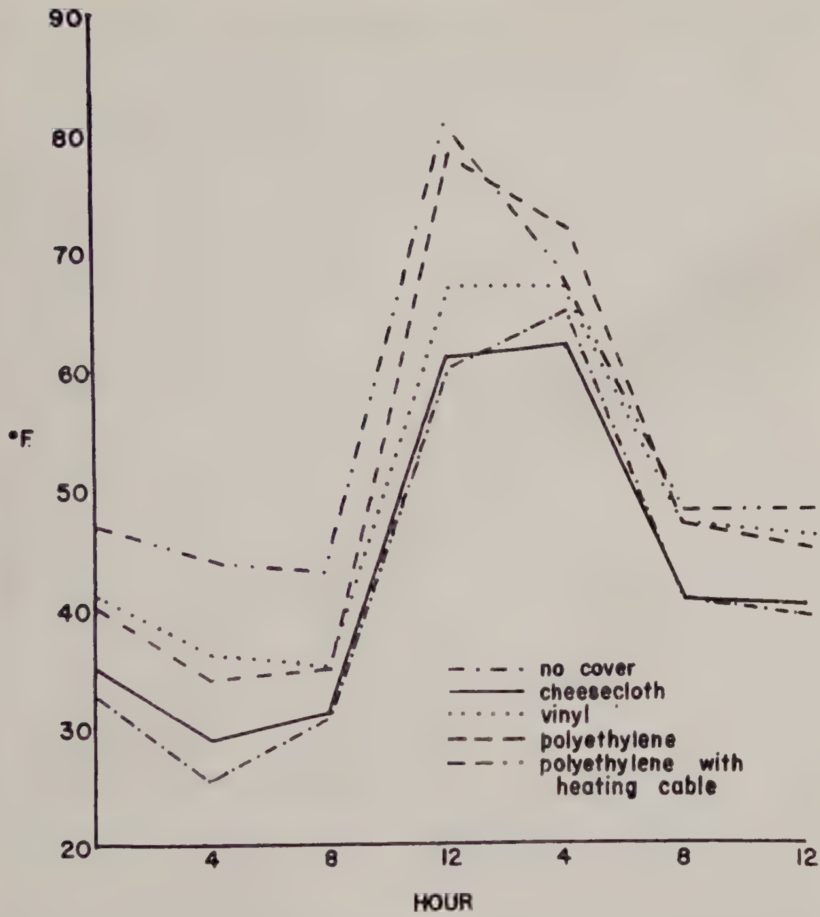

Figure 1.—Temperatures (°F.) 3 inches above the soil surface at 5 locations, Jan. 23, 1959. Gainesville, Florida.

morning and late afternoon was slightly lower. Temperatures under the plastic covers were higher than those under cheesecloth, but differences were slight around sunup and sundown. The soil heating cable under the polyethylene cover, as would be expected, brought about higher night temperatures. Table 4 shows light transmission of the various covers. Condensation on the plastic covers reduced light transmission to about that of cheesecloth.

Experiment 2

The results of this experiment, shown in Table 5, are similar to those of Experiment 1. The plastics produced more plants than cheesecloth, but there were no significant differences between the plastic covers.

Experiments 3, 5, and 6

The effect of different sources of nitrogen on the number of transplants

TABLE 4.—TRANSMISSION OF LIGHT BY THE VARIOUS PLANTBED COVERS, FEBRUARY 8, 1960. GAINESVILLE, FLA.

Cover	Percent Light Transmitted	
	Without Condensation	With Condensation
Cheesecloth (new)	61	—
Cheesecloth (old)	69	—
Polyethylene	77	59
Mylar	89	65
Vinyl	84	70

TABLE 5.—EFFECT OF THICKNESS OF PLANTBED COVER AND VARIETY ON THE NUMBER OF TOBACCO TRANSPLANTS PRODUCED PER SQUARE YARD, 1959 (EXPERIMENT 2). GAINESVILLE, FLA.

Cover	Hicks	402	F22-2	Average
Cheesecloth	198	90	193	160
2 mil Polyethylene	421	384	456	420
3 mil Polyethylene	498	401	385	428
2 mil Vinyl	468	309	394	390
4 mil Vinyl	395	354	344	364
4 mil Vinyl (double)	568	492	414	491
Average	425	338	364	

produced is shown in Table 6. There were highly significant differences between the sources of nitrogen in cheesecloth-covered beds, but not in the polyethylene covered bed. Hoagland's solution in both years and 6-9-3 in 1960 were the best treatments.

Dry weight of the plants, another measure of productivity, is also shown in Table 6. Practically the same trend in decrease in number of transplants is shown in the decrease in dry weight of the tobacco seedlings.

The nitrate levels of the different plots (Table 7) also show more nitrate nitrogen in the plots fertilized with Hoagland's solution. Comparison of the nitrate levels of the soil under the two covers indicates that leaching is a factor that influences the quantity of available nitrogen in tobacco plantbeds.

Experiments 7 and 8

The results of these experiments are shown in Tables 8 and 9. There were no significant differences in number of plants produced; however, the plots receiving the more numerous applications of fertilizer had a tendency to produce most plants.

Table 9 shows the dry weight determinations in Experiment 7. Rates of the two fertilizers did not show consistent trends, but increasing the number of applications caused the weight of the plants to increase.

Table 12 and 13 show the rainfall and average temperature for 1959 and 1960. These data were collected at the U. S. Weather Bureau Stations.[3]

[3]Courtesy of K. D. Butson, State Climatologist.

TABLE 6.—EFFECT OF SOURCE OF NITROGEN ON THE NUMBER OF TRANSPLANTS PRODUCED PER SQUARE YARD WITH POLYETHYLENE (P) AND CHEESECLOTH (C) COVERS, AND ON THE DRY WEIGHT OF SEEDLINGS WITH CHEESECLOTH, 1959 AND 1960 (EXPERIMENTS 3, 5, AND 6). GAINESVILLE, FLA.

	Number of Transplants				Weight/Plant (gm)
	1959	1960			1960
Source of Nitrogen	C	C	P	Average	C
Hoagland's Solution	652	112	401	388	0.885
Sodium Nitrate	211	66	261	179	.363
Ammonium Nitrate	167	71	317	185	.371
Ammonium Sulfate	150	94	296	180	.416
Ammonium Sulfate and Sodium Nitrate	175	80	262	172	.368
Urea	164	----	----	164	----
6-9-3	----	105	370	238	.458
Average	253	88	318		

TABLE 7.—EFFECT OF SOURCE OF NITROGEN AND PLANTBED COVER ON THE NITRATE LEVEL IN TOBACCO BEDS, MARCH 4, 1960 (EXPERIMENTS 5 AND 6). GAINESVILLE, FLA.

	Nitrate Level	
Source of Nitrogen	Cheesecloth	Polyethylene
Hoagland's Solution	High	High
Sodium Nitrate	Low	Medium
Ammonium Sulfate	Very Low	Low
6-9-3	Low	Medium

TABLE 8.—EFFECT OF SOURCE OF NITROGEN, RATE OF FERTILIZATION, AND NUMBER OF APPLICATIONS ON THE NUMBER OF TRANSPLANTS PER SQUARE YARD, WITH POLYETHYLENE (P) AND CHEESECLOTH (C) COVERS (EXPERIMENTS 7 AND 8), 1960. GAINESVILLE, FLA.

	Rate	Number of Applications									
Source of	(Lbs. N/	1		2		4		8		Average	
Nitrogen	Sq. Yd.)	P	C	P	C	P	C	P	C	P	C
Hoagland's Solution	0.06	40	54	16	40	48	62	28	54	33	52
	.09	50	38	72	56	82	104	44	142	62	85
	.12	36	44	78	24	64	134	122	70	75	93
	Average	42	45	55	40	65	100	65	89	57	77
Sodium Nitrate	.06	32	40	50	32	68	50	104	104	64	56
	.09	42	38	60	66	50	114	108	100	65	80
	.12	38	52	28	50	44	66	96	126	52	70
	Average	37	43	46	49	54	77	103	110	60	69

TABLE 9.—EFFECT OF SOURCE OF NITROGEN, RATE OF NITROGEN FERTILIZATION AND NUMBER OF APPLICATIONS ON THE DRY WEIGHT OF TOBACCO SEEDLINGS GROWN UNDER A CHEESECLOTH COVER, 1960 (EXPERIMENT 7). GAINESVILLE, FLA.

	Weight Per Plant (Grams)						
	Rate (Lbs. N/Sq. Yd.)			Number of Applications			
Source of Nitrogen	0.06	.09	.12	1	2	4	8
Hoagland's Solution	0.718	.522	.719	.266	.295	1.016	1.034
Sodium Nitrate	.789	1.607	.664	.227	.375	1.386	2.068

which is located only about a mile from the Tobacco Unit. The purpose of Tables 12 and 13 is to show the weather conditions under which the plants were grown.

Experiment 9

Results of this experiment are shown in yield, value, and average price (Tables 10 and 11). The plants that were pulled and set the same day (check) produced much higher yields than any other treatment. There was a consistent decrease in yield, as the time from pulling until transplanting was increased. Highly significant differences existed between the check and all other treatments, and between the number of days from pulling to transplanting. There were significant differences between the materials used to initiate root growth. No interactions were found.

DISCUSSION

Results are discussed according to the variables tested rather than by experiments.

TABLE 10.—EFFECT OF NUMBER OF DAYS FROM PULLING TO TRANSPLANTING OF TOBACCO ON THE YIELD, PRICE, AND VALUE PER ACRE, 1960 (EXPERIMENT 9). GAINESVILLE, FLA.

Days	Yield (Lbs/A)	Price ¢/Lb)	Value ($/A)
0 (Check)	2354	63.8	1502
2	2155	64.2	1384
4	1901	63.8	1212
6	1839	63.1	1161
8	1434	63.8	915

TABLE 11.—EFFECT OF TREATMENT DURING THE PERIOD BETWEEN PULLING AND TRANSPLANTING ON THE YIELD, PRICE, AND VALUE OF TOBACCO, 1960 (EXPERIMENT 9). GAINESVILLE, FLA.

Treatment	Yield (Lbs/A)	Price (¢/Lb)	Value ($/A)
Hoagland's Solution	1995	63.4	1265
Rootone	1692	64.1	1084
Control	1810	63.8	1155

Plantbed Covers

In every experiment plastic films were superior to cheesecloth as plantbed covers. This superiority was measured in faster germination, more plants, faster plant growth, more vigorous plants, and protection from leaching rains. Benefits not measured include protection from damage by freezing temperatures and reduction of damage by blue-mold.

Most of the benefits of plastic covers can be attributed to the higher temperatures that exist under them. Tobacco plantbeds under cheesecloth must be sown in December or early January in order to have plants large enough to set in March or April. Went (25) stated that the optimum night temperature for tobacco is 30° C. when the plants are very young, and somewhat lower for older plants. Temperatures shown in Table 12 are considerably below this optimum mentioned by Went. Night temperatures of 30° C. may not necessarily be the optimum for seedling production, since some hardiness is required for transplants.

It is evident that the plastic covers produced a more optimum plantbed environment than did the cheesecloth (Figure 1). Detailed figures are not presented, but daytime temperatures under plastic were as much as 40° to 50° F. higher than those under cheesecloth. Night temperatures were 5° to 10° F. higher. The temperature increase under the plastic was directly related to the amount of sunshine. On rainy or very cloudy days, there were no temperature differences between covers.

On some days the temperatures under the plastic covers went to 120° to 125° F. This temperature would be expected to be detrimental, but as long as adequate soil moisture was available, no damage to the plants was observed. The lack of damage is possibly due to the high humidity under the covers and perhaps to the hardiness of the young tobacco plants as well.

The prevention of leaching rains by the plastic covers no doubt kept the plantbed soil in a higher state of fertility. The results shown in Table 7 indicate this. The root systems of plants growing under plastic film—located for the most part in the top inch of soil—were more fibrous and had shorter taproots than those of plants growing under cheesecloth.

Two major advantages of plastic covers over cheesecloth covers for tobacco plantbeds are: (1) less labor will be required, since the sowing of the seed can be delayed three to five weeks, and (2) the number of days required to grow plants to transplantable size can be predicted rather accurately. The transplanting date can be selected, and the plantbeds sown approximately 60 days before this date.

Measurements of light transmission through the various covers (Table 4) show that there is little difference in the materials, when the layer of condensed water on the underside of plastic covers is considered. This layer of water may vary in amount during a 24-hour period, but it is almost always present, and it appears that it affects the transmission of light as much or more than does the plastic alone. The polyethylene cover transmitted less light than the other plastics, because it is not as clear as they are, but has a whitish cast in the material. The lower light intensity under polyethylene, compared to that under other plastic covers is possibly the reason for the greater number of plants under this cover.

As shown in Table 5, the thickness of the plastic cover did not seem to affect the number of plants produced. The ease of handling, resistance to tearing, and price seem to be the most important factors to consider

where thickness is concerned. The plots with the covers of two layers of 4 mil vinyl had very high plant populations, presumbaly because light transmission was reduced, and the pocket of trapped air prevented rapid temperature changes.

The electric heating cable with the polyethylene cover was not used in 1960 because it offered no improvements in plant production over the polyethylene cover alone in 1959. Seed germination was faster when the heating cable was used, but plant growth was not improved. The added heat hastened loss of soil moisture.

There does not seem to be any great differences among plastic covers as far as plant production is concerned. The temperatures under the different plastic covers did not vary greatly, either during the day or at night.

For the period of time they were in use, it was not necessary to replace any cover because of weathering breakdown of plastic. Storage and re-use of the plastic film was not attempted in this series of tests. Adhesives and bonding materials are available for the repair of torn plastic film.

Seeding Dates

Since the plastic covers reduce the time needed to produce transplants, a study of seeding dates was necessary. The 20-day intervals in seedings in 1959 were selected in order to determine how long it would take to produce the transplants with the different covers. This was also a consideration in 1960, but the seeding dates selected were such that date of transplanting could be studied.

The number of transplants produced were significantly decreased as the date of seeding was delayed. This consistent decrease was due to the warmer, longer, and usually drier days later in the year. With the later seedings, it was difficult to keep the beds moist enough for good germination of the seed.

The effect of the changing weather conditions is shown in Table 3. The weather data shown in Table 12 explain the variations in Table 3. Since the cheesecloth cover offered less protection from the weather than the plastic covers, more variation resulted with the different seeding dates. A significant interaction of covers and dates was found in Experiment 1. The plastic covers, by keeping the plantbed environment more nearly constant, reduced this variation. The more constant environment under the plastic covers was, no doubt, the reason for close agreement of the number of days required to produce transplants.

TABLE 12.—AVERAGE MONTHLY TEMPERATURES AT THE TOBACCO UNIT DURING THE PLANTBED SEASON, 1959 AND 1960, GAINESVILLE, FLA.[1]

Month	1959		1960	
	Maximum	Minimum	Maximum	Minimum
January	68.9	41.8	69.4	43.2
February	75.4	54.6	70.2	43.4
March	73.3	49.9	72.1	44.7
April	81.2	57.5	83.1	57.2
December	68.4	44.5	...	...

[1]U.S.W.B. Records

Twenty-five days after the first seeding date in 1959, some of the seed had not germinated under the cheesecloth cover (Table 1). This was not the case with the later seeding dates, nor with the plastic covers. It can be concluded from this that much of the time needed to produce transplants with early seeding dates under cheesecloth is taken up by seed germination.

Varieties

The most interesting, but not always significant, difference between varieties was the relatively poorer performance of 402 with the cheesecloth cover. This poorer performance was exhibited in every experiment in which variety was a variable. The 402 variety is not generally considered to have a great deal of seedling vigor. Since it was exposed to more extreme conditions under cheesecloth, this lack of seedling vigor became critical. The plastic covers offer a more ideal environment for plant growth. The lack of seedling vigor in the 402 variety would not be as critical under the plastic as under cheesecloth.

Experimental plots at the Tobacco Unit were the source of F22-2 seed, whereas commercial seed of Hicks and 402 were used. Difference in seed quality is the most likely reason for the lower plant populations that were sometimes found with the F22-2 variety.

When the F22-2 seedlings in cheesecloth-covered beds did not have ideal growing conditions in the later stages, their leaves became much longer and narrower than usual. The Hicks variety acted similarly, but to a lesser extent.

Other than those mentioned above, no differences among varieties showed up in the plantbed. Most varietal differences are exhibited in mature plants.

Sources of Nitrogen

On sandy soils, such as the Lakeland fine sand on which these experiments were conducted, excessive leaching of soluble fertilizer salts may occur. The nitrate ion is highly mobile and therefore easily leached when excessive rainfall or irrigation occurs. Nutrients become unavailable to the tobacco seedling when they are leached below the top two or three inches of soil, since this is the maximum depth to which the majority of the roots penetrate. Usually more than sufficient nitrogen is applied to plantbeds, but leaching may cause a scarcity of this element. A large part of the effects of different sources of nitrogen is simply due to differences of the quantities of available nitrogen in the root zone.

The apparent superiority of Hoagland's nutrient solution in producing transplants, in the sources of nitrogen experiments, was probably due to the presence of ample quantities of available nitrogen as well as of other nutrients. Almost all the nitrogen in Hoagland's solution is in the nitrate form, which is readily available to the tobacco plant. Since Hoagland's solution was applied at frequent intervals, there was never a scarcity of nitrogen. In every experiment that included Hoagland's solution, except Experiment 6, every plant in the plots receiving Hoagland's solution, that survived until transplanting time was large enough to pull. Also, all plants were pulled within about a ten-day period. All plants were more vigorous and stronger than plants produced with other fertilizers.

The results of ammonium nitrate and the ammonium sulfate-sodium nitrate (one-half of the N from each source) treatments were similar, prob-

ably because the nitrogen status was nearly the same in both cases. These plots were not as productive as those treated with Hoagland's solution and sodium nitrate in Experiment 3, possibly because of incomplete conversion of the ammonium nitrogen.

Fumigation with methyl bromide kills nitrifying organisms (14), which makes a reestablishment of these organisms in the soil necessary before conversion of nitrogen compounds to nitrates is possible. The low temperatures under the cheesecloth covers were not as conducive to nitrification as the higher temperatures under the plastic cover in Experiment 6, where ammonium sources were somewhat better. This may be the case with the ammonium sulfate and urea plots. The urea nitrogen is rapidly changed over to the ammonium form; therefore, ammonium sulfate and urea are essentially sources of only ammonium nitrogen.

In Experiments 5 and 6, the relative success of the 6-9-3 treatment may have been due to choice of not only the nitrogen sources, but also of the other materials. The 6-9-3 was formulated exclusively for tobacco plantbeds.

The results of the nitrate determinations (Table 7) indicate that slow nitrification and or leaching of nitrates must have occurred. Although it is possible that plenty of ammonium nitrogen was present, the soil tests showed little nitrate nitrogen in the ammouium sulfate plots. Leaching and/or slow nitrification may be the reason for the presence of low nitrates in the sodium nitrate and 6-9-3 plots. The Hoagland plots were high in nitrates because nitrate nitrogen was added at frequent intervals. Much more detailed experiments would be required for confirmation of these conclusions.

The superiority of plant production in Experiment 6 as compared to Experiment 5 was mostly due to the plastic cover. The polyethylene cover prevented leaching from rainfall and brought about faster growth rates due to higher temperatures in the bed. This, no doubt, resulted in more effective use of the fertilizer. That leaching was a factor is indicated by the higher level of nitrate nitrogen where the polyethylene cover was used (Table 7).

Rate of Fertilization and Number of Applications

Little difference in plant growth was found between plots treated

TABLE 13.—RAINFALL AT THE TOBACCO UNIT, 1959 AND 1960, GAINESVILLE, FLA.[1]

	1959		1960	
	Period	Accumulative	Period	Accumulative
January 1-15	2.73	2.73	1.13	1.13
16-31	.99	3.72	2.63	3.76
February 1-15	2.65	6.37	.91	4.67
16.28	1.72	8.09	2.85	7.52
March 1-15	5.24	13.33	2.93	10.45
16-31	5.24	18.57	4.55	15.00
April 1-15	2.30	20.87	.57	15.57
16-30	1.82	22.69	2.16	17.73

[1]U.S.W.B. Records

with sodium nitrate and Hoagland's nutrient solution in Experiments 7 and 8. Both fertilizers provided only nitrate nitrogen for the most part. Since the beds have been used for a number of years, residual fertility may have prevented the development of differences.

The lack of substantial increases, or in most cases, decreases in plant population and growth indicated that the highest rate of fertilization was detrimental, especially in plots receiving only one or two applications. The decrease in plant performance with increased fertilization was probably due to damage from the excess soluble salts.

The increased growth of plants obtained when split applications of fertilizer were used is due to an ample supply of nitrate nitrogen at all times. There was a possible lack of nutrients at times with the more numerous and less concentrated applications.

Another observation that indicates leaching is a problem on sandy soils is the similarity in root systems of plants grown under a plastic cover, where leaching does not occur, and those grown in plots where fertilizer is added in several applications during the plantbed season. This root growth is characterized by numerous small feeder roots near the soil surface, and not by long taproots found on plants grown where nutrients are limited.

Delayed Transplanting

Experiment 9 was the only source of information on delayed transplanting. Farmers who have their own beds usually set out their plants the same day they are pulled. If purchased, the number of days between pulling and transplanting will depend on the distance the plants must be transported. The results in Table 10 indicate a loss in yield of about 100 pounds for each day elapsing between pulling and setting the plants. Root growth during the heeling-in period was encouraged in this test; whereas, growth is not usually encouraged with shipping seedlings. It is possible that lack of root growth during the period between pulling and transplanting could bring about results different from those found in this study, but there has been no evidence to support this theory.

Significant differences existed between the materials used to induce rooting. Nutrients were apparently beneficial to the plant at this time, since Hoagland's solution was the superior treatment. Plants treated with Rootone grew fewer roots during the heeling-in period, and subsequently produced lower yields than plants from other treatments.

SUMMARY

Eight experiments that dealt with tobacco plant production were conducted in 1959 and 1960. Plantbed covers, thickness of covers, seeding dates, varieties, sources and rates of nitrogen, and number of applications of fertilizers were the variables tested.

In every experiment, plastic films were superior to cheesecloth as plantbed covers. This superiority was measured in faster germination, more plants, faster plant growth, more vigorous plants, and protection from leaching rains. Benefits not measured include protection from damage by freezing temperatures and reduction of damage by blue-mold. Plastic films make it possible to predict the length of time (55-56 days) necessary to produce good transplants, despite the weather conditions.

As far as plant production was concerned, the thickness of the plastic cover had little effect. Early seeding dates produced more plants, mostly because the seed germinated and the plants had become established before the warm, dry days of spring began. The major difference in varieties was the relatively poor performance of the 402 variety grown under cheesecloth.

Hoagland's nutrient solution was tested with other fertilizer materials under cheesecloth in 1959 and was significantly better; however, sodium nitrate produced comparable results when applied in a similar manner in 1960. High rates of nitrogen were usually no better than medium rates. More frequent applications of nutrients helped to reduce the leaching losses under cheesecloth.

Results were highly significant in favor of transplanting seedlings as quickly as possible after they were pulled from the plantbed.

LITERATURE CITED

1. Beaumont, A. B. The toxicity of ammonium compounds for tobacco. Proc. Second Int. Cong. Soil Sci. IV:65-78. 1930.
2. Carr, J. M. Tobacco plant production in the Coastal Plain of Georgia. Georgia Coastal Plain Exp. Sta. Bul. 38. 1943.
3. Clark, F. and G. M. Volk. Plant beds for flue-cured tobacco. Florida Agr. Exp. Sta. Circ. S-44. 1952.
4. Dean, C. E. The effects of supplemental heat and light on the production of tobacco seedlings. Unpublished MS Thesis, Univ. of Fla. 1957.
5. ——————, H. Seltmann and W. G. Woltz. Some factors affecting root development by transplanted tobacco plants. Tobacco Sci. 150 (6):22-28. 1960.
6. Furuya, M. and M. Sasaki. Comparisons of various growing methods of tobacco seedlings. Bul. Okayama Tob. Expt. Sta. Japan Monop. Corp. No. 12:17. 1956. (Original not available for examination abstracted in *Abstracts of Researches. Tobacco, Salt, Camphor.* Tokyo: Japan Monop. Corp. 1:1. 1958.
7. Garner, W. W. The Production of Tobacco. Rev. 1st Ed. New York. The Blakiston Co. 1951.
8. Henderson, R. G., E. M. Matthews, and W. A. Jenkins. Tobacco plantbed management. Virginia Agr. Exp. Sta. Bul. 384. 1945.
9. Hoagland, D. R. and D. J. Arnon. The water-culture method for growing plants without soil. California Agr. Exp. Sta. Circ. 347. 1950.
10. Kubota, M., T. Hiruma and K. Hoshino. On the forms of vinyl film as the cover of seed-bed of tobacco plants. J. Tob. Prod., Japan, No. 5, 28. 1955. (Original not available for examination; abstracted in *Abstracts of Researches. Tobacco, Salt, Camphor.* Tokyo: Japan Monop. Corp. 1:1. 1958.)
11. Leone, I. A. and J. W. Shive. Effects of variations in N and P nutrition on renewal of growth in transplanted tomato seedlings. Soil Sci. 68: 237-250. 1949.
12. McCants, C. B. and W. G. Woltz. Urea and calcium cyanamid in tobacco plant beds. North Carolina Agr. Exp. Sta. Bul. 105. 1954.
13. ——————. Fumigated soil needs nitrate nitrogen. North Carolina Agr. Exp. Sta. Res. and Farm 17 (3):4. 1959.
14. ——————, E. O. Skogley and W. G. Woltz. Influence of certain soil fumigation treatments on the response of tobacco to ammonium nitrate forms of nitrogen. Soil Sci. Soc. Amer. Proc. 23:466-469. 1959.
15. Moodie, F. B. Tobacco culture. I Preparing plant beds and sowing seed. Florida Farmer and Fruit Grower. 1 (3):19. 1887.
16. Mauraoka, Y. and K. Ohori. Physiological studies on the development of tobacco plant. III. On the characters and developmental processes of tobacco seedlings grown under high and low temperature conditions. Bul. Okayama Tob. Exp. Sta., Japan Monop. Corp., No. 13, 14. 1956. (Original not available for examination; abstracted in *Abstracts of Researches. Tobacco, Salt, Camphor.* Tokyo: Japan Monop. Corp. 1:15. 1958.)
17. Pettis, A. M. Yield and quality of flue-cured tobacco as affected by heat-light treatments in the seed-bed. Unpublished MS Thesis. Univ. of Fla. 1956.
18. Powell, R. D. Effect of light and temperature on germination of tobacco seed. (abstract) Plant Physiol. 33 (sup.):xxiii. 1958.
19. Saunders, E. S. The effect of seed bed covers, supplemental heat, and chilling on tobacco production. Unpublished MS Thesis, Univ. of Fla. 1960.

20. Steinberg, R. A. Low temperature induction of flowering in a *Nicotiana rustica* x *N. tabacum* hybrid. Plant Physiol. 28: 131. 1953.
21. ——————. Premature blossoming: Effects of vernalization, seedling age, and environment on subsequent growth and flowering of transplanted tobacco. Plant Physiol. 27:745-753. 1952.
22. Tilley, N. M. The Bright-Tobacco Industry 1860-1929. pp. 37-43. New York; Van Rus Press. 1948.
23. Toole, E. H., V. K. Toole, H. A. Borthwick and S. B. Hendricks. Interaction of temperature and light in germination of seeds. Plant Physiol. 30:473-478. 1955.
24. Waksman, S. A. Soil Microbiology. pp. 62. New York; John Wiley and Sons. 1952.
25. Went, F. W. Experimental control of plant growth. pp. 113-114. Waltham, Mass. Chronica Britanica Co. 1957.
26. Woltz, W. G. Sources of nitrogen for flue-cured tobacco beds. In sources of nitrogen for crop production. S. L. Tisdale, Ed. pp. 26-32. North Carolina Agr. Exp. Sta. Tech. Bul. 96. 1952.

Alfalfa Persistence Studies[1]

S. H. WEST and G. M. PRINE[2]

INTRODUCTION

The poor quality of pasture and hay available for livestock in Florida is reflected in the low grade of grassfed beef and inefficient milk production. In other areas of this country, legumes are used to improve the quality of forages primarily because their higher protein content improves the nutritive value (3). The protein level of grasses is especially low if they are not properly fertilized with nitrogen. In this respect, legumes have an advantage because of their nitrogen fixing ability.

Probably less than 10% of the pastures in Florida contain satisfactory legume stands. By far the most important reason for the low acreage is poor persistence. Legumes such as alfalfa, red clover and some white clovers which are grown extensively as perennials in other states produce little after the first seeding year. Farmers are not willing to seed annually and assume the risk of poor stands and poor production. Therefore, researchers are challenged to determine why legumes fail and how they can be managed to persist under Florida conditions.

The climate of Florida is warmer than that in most legume producing areas. The theory that legumes fail here because of the extremes of heat is often discarded because the daytime temperatures of our hottest days are usually not higher than those in areas where legumes are grown successfully (Table 1). However, our summer nights are usually warmer and in winter, both day and night temperatures are higher. Furthermore, and perhaps of most significance, the total number of warm days and nights is greater in Florida. Thus it is reasonable to speculate that the higher temperatures over longer periods may be one of the factors contributing to poor legume persistence.

The level of carbohydrate reserve in the root has been correlated with persistence in some legumes (6). The heat in the climate of Florida would

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TABLE 1.—THE CLIMATE OF FLORIDA COMPARED TO THAT OF OTHER LEGUME PRODUCING AREAS.[3]

	Ave. Maximum Temp. (°F)		Ave. Minimum Temp. (°F)	
	Merced, California	Gainesville, Florida	Merced, California	Gainesville, Florida
August	95	91	58	71
January	54	69	34	47

	Average Days/Year			
	Maximum Temp.		Minimum Temp.	
	32°F or below	90°F or above	32°F or below	65°F or above
Ames, Iowa	52	24	151	36
Gainesville, Fla.	0	96	8	157

[3]*Climatological Data,* United States Weather Bureau. 1951-1955.

tend to reduce this root reserve. One reason for this would be increased respiration. For each 18° F. increase in temperature between 50-85° F., the respiration rate of plants goes up 2 to 2½ times (2). Respiration is the oxidation of carbohydrates to energy which may in turn be used for growth or wasted as heat. A second reason is the longer duration of the high temperature causing the plant to respire at a high rate over a longer period of time. Third, the faster growth brought about by the increase in respiration may result in more frequent harvest. Thus, a greater percentage of the carbohydrate from photosynthesis would go into topgrowth and less would be available to replace the root reserves. Fourth, under Florida's climatic conditions, legumes are harvested sooner after seeding thereby reducing the time available for root growth and food storage.

The effect of climate on the carbohydrate level in alfalfa was observed throughout the season at Gainesville, Fla. Management practices designed to maintain high root reserves were also compared. A method for selecting alfalfa plants resistant to high temperatures is also reported in this paper.

METHODS

Experiment I

Alfalfa (variety Hairy Peruvian) which had been seeded the previous fall on Arredondo loamy fine sand was selected for weekly sampling. At seeding time, 1200 pounds of 0-10-20 with 1.32 percent boric oxide, 1500 pounds of calcic and 1000 pounds of dolomitic limestone were applied per acre. On May 8 and July 2, 250 and 400 pounds of 0-10-20 per acre, respectively, were added. At the beginning of the experiment, four stakes were located at randon in the uniform stand. At weekly intervals beginning on June 10, 1959, a sample of two plants was taken from eight locations at each of the four stake sites. These sixteen plants were composited to make a top and root sample from each stake location. The tops of the plants were harvested from the crown up. Root samples consisted of the crown and root to a depth of four inches. Before weighing, the samples

were dried in an oven at 170° F. for 96 hours. The entire sample was ground in a Wiley mill and an aliquot was removed for total available carbohydrate determination using the Taka-Disease enzyme for hydrolysis according to the method of Weinmann (5). The alfalfa was harvested when it reached the 1/10 to 1/2 bloom stage.

Experiment II

A split plot design experiment was initiated on another stand of alfalfa of the same seed source, seedbed preparation and pre-plant fertilization as above. The main plot treatments consisted of 70 and 140 pounds per acre of K_2O and 140, 180, 220 and 260 pounds per acre of P_2O_5 in all combinations. These fertilizers were applied after each of the first four harvests. One-half of each fertilizer plot was harvested each time at a 2-inch height and the other half was harvested at a 4-inch height. Root samples from all fertilizer and clipping treatments were harvested and analyzed for carbohydrate as in Experiment I. Temperatures were measured at various heights in the two cutting treatments by copper-constantant thermocouples connected to a Brown recording potentiometer.

Experiment III

The soil floor of an unpainted greenhouse was seeded in May 1960 with Hairy Peruvian alfalfa. Soil and air temperatures were determined as in Experiment II. After 6 weeks the respiration rates of 20 leaf discs from plants that had grown to a height of 15 to 17 inches and from plants that had grown only 2 to 3 inches were measured by standard manometric procedures. Respiration rates were determined first at 86° F. and then at 104° F. on the same discs. The manometers continued to shake while the temperature of the water bath was being increased from 86 to 104° F.

RESULTS AND DISCUSSION

Experiment I

During July and August the stand of alfalfa in this test became too thin to be of value as a hay or pasture crop. Progressively, the regrowth of the surviving plants became slower. According to Willard, *et al.* (7), this is an indirect indication of a low level of root reserve. Leaves dropped from the stems before maturity until only a few remained near the tip and these were often yellow in color.

The total carbohydrate content of the roots (Figure 1.) declined sharply immediately after each harvest and then increased as growth resumed. This phenomenon was observed long ago (1) and would be expected as respiration of stored plant food is necessary for initiation of new growth. However, the level to which the carbohydrate dropped was lower with each successive harvest until after the September 10 cutting the content had decreased form the initial 40 to 14%. Although the carbohydrate level gradually increased over the period between harvests, the original high level was never reached. Furthermore, the length of time required for the root reserve level to increase was greater as the season progressed. Only 3 weeks were required after the May harvest whereas 7 weeks were necessary after the September cutting. It should be noted that in Pennsylvania, Sprague *et al.* (4) found the carbohydrate content of alfalfa decreased

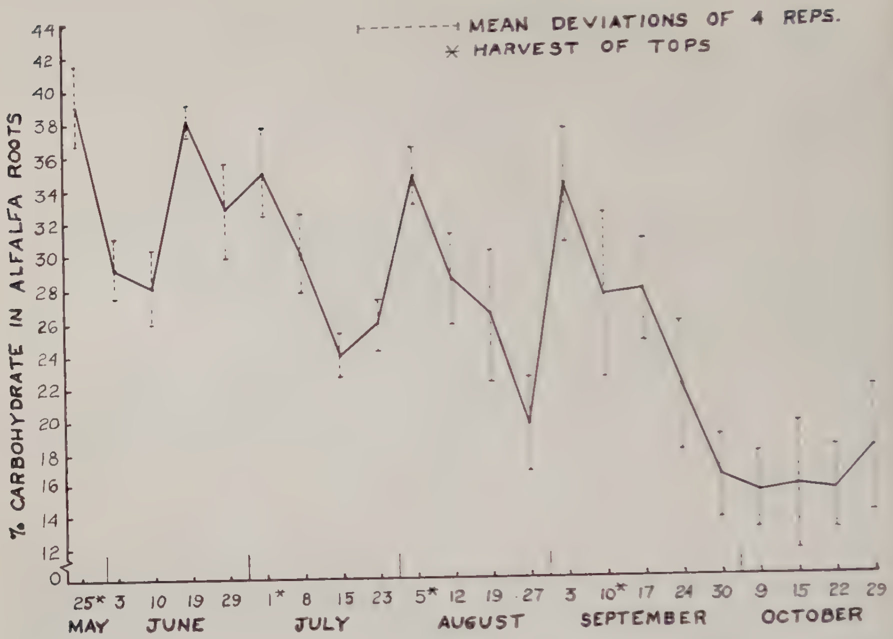

Figure 1.—Carbohydrate content in roots of Hairy Peruvian Alfalfa during 1959 growing season.

rapidly for 1 week and then increased for 4 weeks at which time it reached the original level.

A total carbohydrate analysis on a Taka-Disease hydrolysate would include sugars from many plant constituents such as starches, nucleic acids and nucleotides. Therefore, the 14% level of carbohydrate would represent almost no free sugars available for energy or carbon skeletons for synthesis and growth. Furthermore, because of the virtual starvation level of sugars in the plant roots, other carbohydrate containing compounds essential to structure and normal metabolism may have been used in the excessive respiration, thus impairing cell function and subsequent growth. In addition, plants reduced to this level of metabolism are more susceptible to disease and insect infestation and buildup.

Experiment II

The alfalfa in Experiment I received management similar to what a farmer would employ. Apparently under this treatment in our climate the carbohydrate level essential to growth cannot be maintained and stands fail. One of the most obvious solutions to this problem, it seems, is to change the cultural practices of our legumes to favor storage of root reserves. Data from Experiment II indicate that the level of carbohydrate can be altered by management (Figure 2). The root carbohydrate level response to fertilizer was so inconsistent and variable, little could be concluded. However, regardless of the fertilizer treatment, the carbohydrate content was highest in the roots of alfalfa that had been harvested at a 4-inch height. This practice leaves more of the photosynthetic apparatus intact which would allow the plant to produce more of its needed carbo-

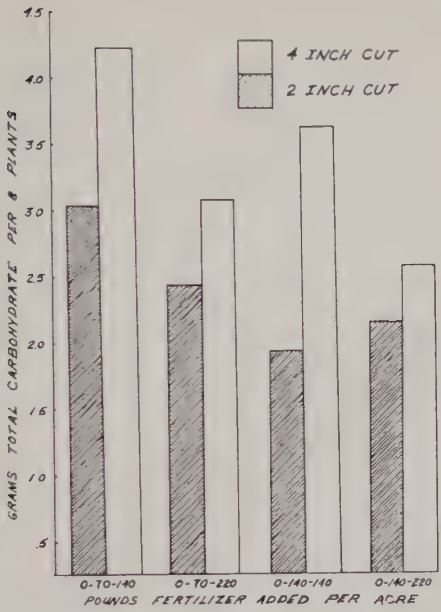

Figure 2.—Carbohydrate content of alfalfa roots on June 15, 1959.

hydrate earlier. Furthermore, since 2 inches less stem would have to be produced for the subsequent harvest, less root reserve would be used. Another and probably just as important reason for the higher level of root reserves in the higher cutting is the effect of the tall stubble on the microclimate of the alfalfa plant. As shown in Table 2, the temperature of alfalfa stems at the soil surface was markedly higher during much of the day in the short clipping height. The lower temperature in the tall stubble would cause the respiration rate of the plants to be lower and thus more of the carbohydrate would be conserved.

Experiment III

Selecting and breeding legumes to survive our climate is a second approach to the problem of poor legume persistence that appears to have promise. In this experiment, alfalfa plants were selected for tolerance to heat on the basis of their growth and vigor in a greenhouse in which the temperature reached 120 degrees for as long as 6 hours each day. After 6 weeks of growth, approximately 85% of the plants were 2 to 3 inches tall and were chlorotic, while 15% were 15 to 17 inches tall and were green and vigorous. Respiration rates of leaf discs from the short and tall plants were compared to establish a criterion for the differential growth response. At low temperatures, the respiration rates of the heat tolerant and less heat tolerant plants were similar (Table 3). However, in high temperatures the heat tolerant plants respired markedly slower. The slower use of carbohydrate would permit the plants to conserve their energy for storage and growth and result in better survival. The diminution in respiration rates (Table 3) would be expected even at high temperatures as the leaf discs had available only endogenous carbohydrate for respiratory sub-

TABLE 2.—THE DAYTIME TEMPERATURE OF THE STEMS OF ALFALFA HARVESTED AT TWO HEIGHTS.

Time	Temperature °F at Soil Level (Mean of Duplicates)			
	8:00 a.m.	11:00 a.m.	2:00 p.m.	5:00 p.m.
2″ stubble	82	106	100	89
4″ stubble	82	98	93	86

TABLE 3.—RESPIRATION RATES OF TWO ALFALFA SELECTIONS AT VARIOUS TEMPERATURES.

	Microliters of 0_2/20 discs/hr. (Mean of Triplicates)	
	86°F	104°F
Leaf discs from heat tolerant plants	108.8	68.7
Leaf discs from non-heat tolerant plants	98.4	93.6

strate during the incubation period. Incubation for two hours was required for the determinations over the entire range of temperatures.

SUMMARY

The failure of alfalfa to persist in Florida may be the result of the long duration of warm night and day temperatures. The carbohydrate level of the roots of alfalfa decreased in the summer from 40 to 14%.

Legume persistence may be improved by proper management. Alfalfa cut at a 4-inch height had a cooler microclimate and more root carbohydrate than when cut at a 2-inch height.

Alfalfa plants were selected for heat tolerance on the basis of vigor and growth in high temperatures. The heat tolerant plants respired at a slower rate in high temperatures.

The probable relationship of temperature on respiration rates, carbohydrate reserve and persistence is discussed.

LITERATURE CITED

1. Garver, S. Alfalfa root studies. U. S. Dept. Agr. Bul. 1087. 1922.
2. Meyer, B. S. and D. B. Anderson. Plant Physiology. Second Edition. D. Van Nostrand Co., Inc. New York. p. 408. 1952.
3. Sprague, V. G. Maintaining legumes in the sward. Sixth International Grassland Congress. pp. 443-449. 1956.
4. Sprague, V. G., R. R. Robinson and R. J. Garber. Management of grasslands in the northeastern states. Pennsylvania Agr. Exp. Sta. Bul. 554. 1952.
5. Weinmann, H. Determination of total available carbohydrates in plants. Plant Physiology 22:279-290. 1947.
6. Willard, C. J. Advances in Agronomy, Vol. III. The Academic Press, Inc. New York. pp. 93-112. 1951.
7. Willard, C. J., L. E. Thatcher, and J. S. Cutler. Alfalfa in Ohio. Ohio Agr. Exp. Sta. Bul. 540. 1934.

The Use of Anhydrous Ammonia in the Curing of Hay[1]

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There is a serious need for supplemental forage during the winter months in the cattle industry in Florida and other areas having wet growing seasons. Hay is used widely where it can be cured readily. In Florida and other humid areas, high humidity and frequent, unpredictable rains make hay-curing difficult.

The following study was an attempt to utilize anhydrous ammonia in its capacity as a sterilant to preserve partially-dried forage until curing by natural or artificial means could be completed. An increase in protein content of the forage by ammoniation, as is done with citrus pulp and other feed stuffs, was a possible additional benefit.

METHODS

First, a laboratory study was made to determine the feasibility of using anhydrous ammonia for this purpose. St. Augustinegrass, both green and cured, was packed firmly in quart jars; the jars were closed with one-holed lids. A glass tube attached to an ammonia cylinder was inserted through the hole, and ammonia was released into the forage for five minutes. The jars, with holes left open, were then wrapped in several thicknesses of paper hand towels and held in a 28 C. constant-temperature room for eleven days during which time the temperature inside each jar was measured. Following the temperature-measurement period, 400 ml. of sterile tap water were added to each jar and allowed to mix thoroughly with the forage. The liquid was decanted and plated in 1:1, 1:100 and 1:1,000 dilutions of the original water. Bacteria and fungi were plated on soil extract and rose bengal agar, respectively. Percentages of moisture, extractable ammonia and total nitrogen were determined from separate samples.

Subsequently, two field studies were conducted with baled pangolagrass forage. Forage cured for different lengths of time was used. The first field study involved the use of a single-pronged injector. This was inserted into different parts of the bale. Four rates of ammonia were injected: 0, 0.2, 0.5 and 1.0 pound NH_3-N per 50-pound bale of air-dry forage. Five bales were used for each treatment. The second field study involved the use of a multi-pronged injector. Ammonia treatments were none and 1.0 pound of NH_3-N per 50-pound bale. Bales were treated either with or without a polyethylene cover for comparison. The cover was used to reduce volatilization of ammonia from the bales during treatment and to obtain more even distribution of ammonia throughout the forage. Covers were removed after treatment. The two injectors are shown in Figure 1.

The bales were randomly stacked five deep under a shed after treatment. Temperatures were measured daily until they were essentially the same for all treatments. Temperature measurements were made by in-

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Fig. 1.—Single- and Multi-pronged Injectors Used for Injection of Anhydrous Ammonia into Forage Bales.

serting a thermometer into the ends of the bale to a depth of 6 to 8 inches. Ammoniacal nitrogen in the baled forage was determined by leaching approximately 20 g. of forage from the bale with 400 ml. of 10% NaCl; calculations were based on oven-dry material. The analysis was made at the termination of the temperature-record period at which time the forage was approximately air-dry. An aliquot of the leachate was made alkaline with $Ca(OH)_2$, and the ammonia was distilled into 4% boric acid. Total nitrogen was determined by the Kjeldahl procedure.

RESULTS AND DISCUSSION

Laboratory Study—

Little heating of the forage occurred, as indicated by relatively uniform temperatures. Fungi were essentially eliminated by the ammonia treatment, but the numbers of bacteria were markedly increased as shown in Table 1. The increase in bacteria appeared to result from proliferation of a species which formed small iridescent colonies on the plates. Earlier work in soils[3] showed much the same pattern with an initial reduction in bacterial numbers for two to three days, after which there was a very large increase. Colonies on the plates from soil studies appeared the same as those from the forages. Percentages of dry matter and total nitrogen in the forage are shown in Table 2.

TABLE 1.—NUMBERS OF FUNGI AND BACTERIA IN FORAGE (AIR-DRY BASIS) FROM THE LABORATORY STUDY.

Organism	Green Grass		Cured Grass	
	Untreated	NH_3-Treated	Untreated	NH_3-Treated
Fungi, Thousands/g.	74.3	0.2	119.4	0
Bacteria, Millions/g.	0	212.0	1.9	127.0

[3]Eno, C. F. and W. G. Blue. The effect of anhydrous ammonia on nitrification and the microbiological population in sandy soils. Soil Sci. Soc. Amer. Proc. 18: 178-181. 1954.

TABLE 2.—DRY MATTER AND TOTAL NITROGEN IN ST. AUGUSTINE FORAGE FROM THE LABORATORY STUDY.

Forage Treatments	Dry Matter	Total Nitrogen
	%	%
Green, Untreated	16.7	2.29
Green, NH_3-Treated	18.2	3.66
Dry, Untreated	57.6	2.57
Dry, NH_3-Treated	72.8	3.62

Field Studies—

The initial field study was conducted in July. Forages that had been field-dried 0, 6 and 30 hours and which contained 38, 49 and 57% dry matter, respectively, were used. In general, the temperatures were reduced initially where ammonia was injected (Figure 2). After the initial reduction, temperatures of ammonia-treated bales increased to higher levels than for bales not receiving ammonia.

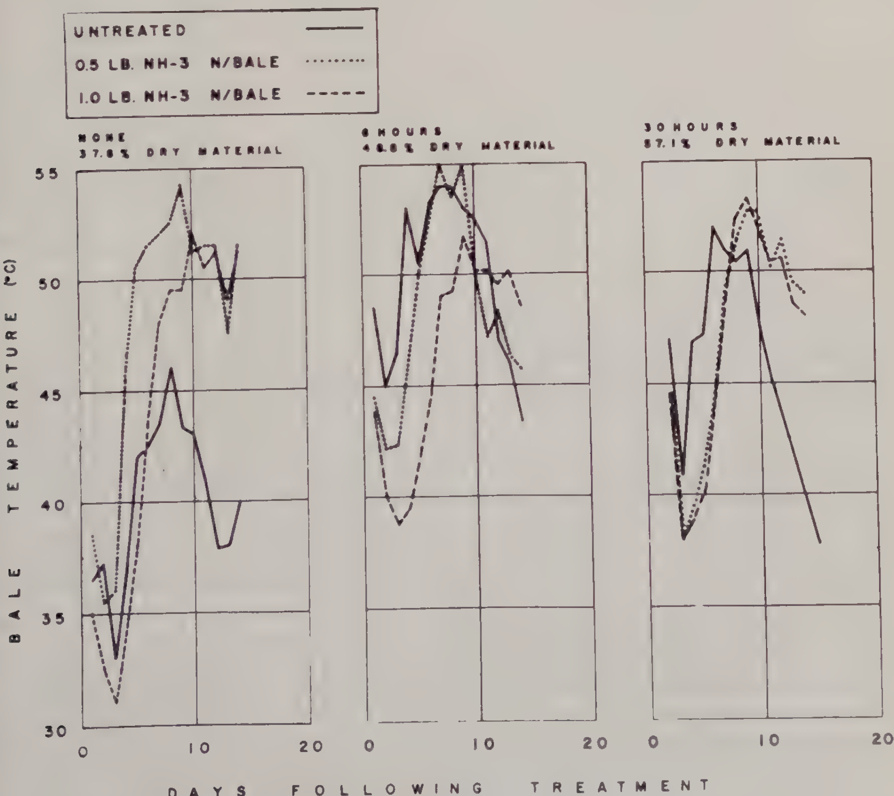

Fig. 2.—The Effect of Ammonia Treatment and Moisture Percentage on the Temperature (°C.) of Pangolagrass Forage Baled in July.

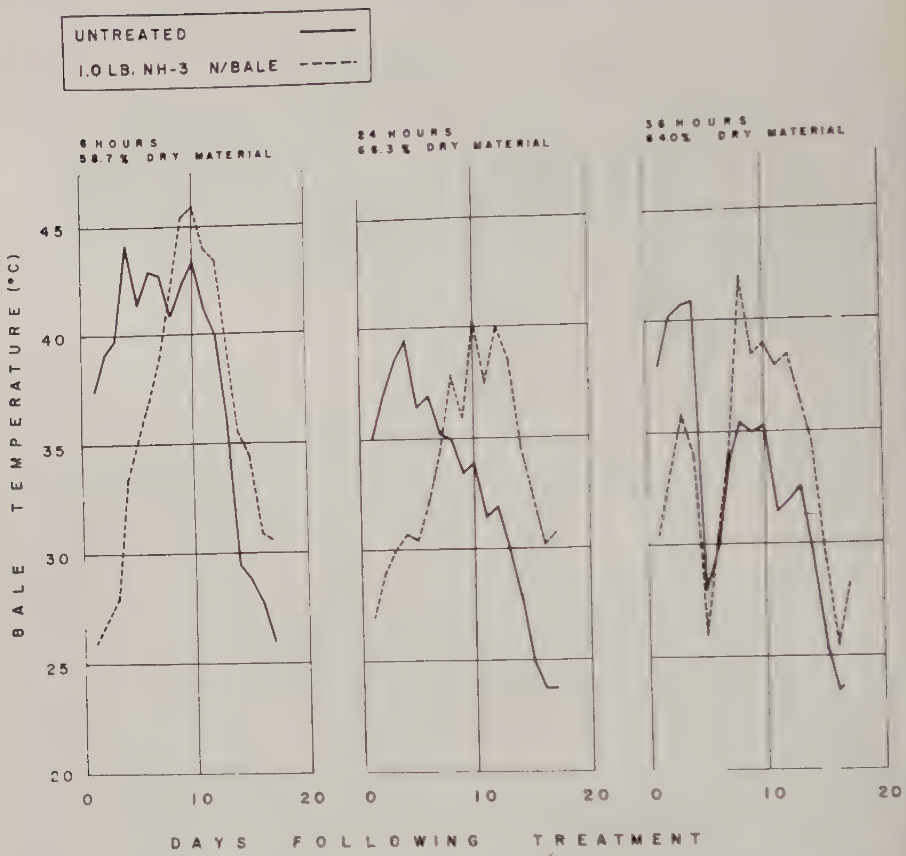

Fig. 3. —The Effect of Ammonia Treatment and Moisture Percentage on the Temperature (°C.) of Pangolagrass Forage Baled in October.

Fungi were reduced to very low levels for all ammonia treatments compared to untreated forage (Table 3). Bacterial numbers are not shown because numbers from all treatments were larger than could be counted on the 1:10,000 dilution plates. Treatment of the forage was incomplete in the initial field study as evidenced by the distribution of the fungi mycelia. Mycelia were not visible in the treated portions of the bales near the injection points; however, at the periphery of the treated portions, the mycelia concentrations were extremely large. Mycelia were fewer and more evenly distributed in the untreated bales.

The amounts of ammonia and total nitrogen in the baled forage at the end of the temperature-measurement period are shown in Table 4. Extractable ammonia and total nitrogen were markedly increased in forage which had had ammonia injections. This demonstrated that the forage could retain ammonia in sufficient concentration to suppress numbers of microorganisms and significantly increase the protein content of forages under field conditions. The efficiency of retention of ammonia by the forage was inversely proportional to the quantity injected.

TABLE 3.—NUMBERS OF FUNGI IN FORAGE (AIR-DRY BASIS) FROM THE FIRST FIELD STUDY.

Bale Treatments	Hours Field-Dried		
	0	6	30
Lbs. NH_3-N/Bale	Thousands/g.		
0	2.7	30.7	177.0
0.2	0.6	0	1.8
0.5	0	0	1.6
1.0	0.2	0	0

TABLE 4.—DRY MATTER, AMMONIACAL NITROGEN AND TOTAL NITROGEN IN FORAGE FROM BALES USED IN THE FIRST HAY-PRESERVATION STUDY.

Field Drying Time	Treatment	Dry Matter	NH_3-N	Total N
Hours	Lbs. NH_3-N/Bale	%	ppm	%
0	None	38	125	0.43
	0.2	38	2,700	1.20
	0.5	38	2,890	0.97
	1.0	38	3,100	0.87
6	None	49	64	0.47
	0.2	49	4,750	0.94
	0.5	49	4,360	1.01
	1.0	40	5,600	1.29
30	None	57	26	0.50
	0.2	57	3,690	0.92
	0.5	57	3,890	0.89
	1.0	57	6,670	1.14

Because of the heterogeneous treatment of the baled forage in the initial field study, a second study was made in October with a multi-pronged injector. Forages were dried 6, 24 and 36 hours and contained 58.7, 66.3 and 64.0% dry matter. Temperatures, as shown in Figure 3, were generally lower than in the July studies as a result of lower air temperatures and probably also because of the use of drier, more mature forage plants. Average maximum and minimum air temperatures were 92.4 and 70.5° F. during the period of record in July, and 77.5 and 61.5° F. during October.[4] On the fifth day of the record period there was a marked drop in bale temperatures which corresponded to two days during which the minimum air temperature was 5.5 degrees below the average minimum. Trends in bale temperatures were very similar to those from the previous field study. The appearance of the interior of the bales was also similar. The nitrogen contents and numbers of microorganisms are not shown for this study due to their similarity to data from the initial field study. Fungal counts did not show inhibition as clearly as did the initial study, but numbers were generally lower in treated bales than in untreated ones. Numbers of bacteria were frequently, but not consistently, larger in treated bales.

[4]Temperature records are for July and October, 1956, and are through the courtesy of Mr. Keith Butson, Climatologist, U. S. Weather Bureau, Gainesville, Fla.

Extractable ammonia and total nitrogen were increased with treatment; but neither to the same extent as in the previous study. Lower concentrations of ammonia probably accounted for less inhibition of fungi and less stimulation of bacteria. The polyethylene cover did not alter concentrations of ammonia nor numbers of fungi or bacteria compared to uncovered bales.

SUMMARY

Anhydrous ammonia was used in an attempt to preserve incompletely-cured forage during inclement summer weather. It had previously been shown to act as a partial sterilant when injected into soils for fertilization purposes.

Relatively high concentrations of ammonia were applied to green and dry forage in the laboratory. Little heating of the forage occurred. Fungi were essentially eliminated by treatment, but numbers of bacteria were increased. Nitrogen in the forage was markedly increased.

In the July field study made with a single-pronged injector, temperatures of treated bales were lower than those from the untreated for the first several days of record due to the cooling effect of volatilizing ammonia. Maximum temperatures of treated bales were higher than for untreated bales. Fungi were essentially eliminated in the treated portions of the bales, but bacterial numbers were greatly increased, apparently due to proliferation of a single species. The ammonia concentrations were frequently above 3,000 ppm, and total nitrogen was essentially doubled by the treatment: from approximately 0.5 to 1.0%.

A second field study was made in October with a multi-pronged injector in an effort to more completely treat the forage. Resulting ammonia concentrations were less than in the original field study. Fungal numbers were suppressed to a lesser extent, and bacterial numbers were somewhat lower in treated bales.

Development of a hay-curing system of this type would be of considerable value in providing supplementary forage and in increasing its protein content. However, anhydrous ammonia, at the concentrations obtained, is only a partial sterilant. Therefore, it appears that the possibility of using anhydrous ammonia alone as a preservative is remote. There may be some potential for its use in conjunction with other materials having fungicidal and bactericidal properties or of using other minerals independently. The recognized need for more supplemental forage and the availability of many chemical compounds having fungicidal and bactericidal properties warrant further study.

Major Insect Problems of Soft (Bast) Fiber Species in South Florida[1]

WILLIAM G. GENUNG[2]

Research on the culture, breeding, diseases and processing of the soft or bast fiber plants[3] has been conducted extensively at the Everglades Experiment Station for nearly two decades by state and Federal workers, and has been reported by Neller (10), Seale *et al.* (12, 13), Pate *et al.* (11), Wilson and Pate (16), Summers (14), and Allison and Randolph (1). The potential strategic importance of certain of these fibers for industrial and national defense uses has stimulated investigations on the various aspects of their production disproportionate to their immediate practicable value in the economy of the state or nation.

Although the commercial production of soft fibers in Florida has practically ceased, at least for the time being, extensive research on the various aspects of their production continues. Kenaf was grown on a commercial scale in Florida in 1951 and 1952 and ramie was so produced for a period of several seasons. In view of the great amount of work reported on the other phases of fiber crop production, a report of the entomological problems was deemed desirable. Although insect problems on these crops have not been intensively studied, insects can be an important factor in their production. The purpose of this report is to discuss the major insects attacking the more important bast fiber species and suggestions for their control, based on more than a decade of observations. It is hoped that the information here presented will be of use to research workers in the United States and to the researcher and commercial producer elsewhere in the Western Hemisphere, particularly, since many of the insects discussed here or related species occur widely in the Neo-tropical region.

Cultural and ecological factors of importance in control will be discussed since insecticides are costly for commercial use on these basically cheap crops although practicable for use by the experimental worker. The commercial producer should take full advantage of the applied ecological aspects in reducing or obviating insect damage. A knowledge of his operation and the economics involved will determine the advisability of using chemical control. The growth habits of these crops are such that use of aerial equipment is the most feasible method of applying insecticides commercially. The insecticides suggested were not observed to produce phytotoxic symptoms under Everglades conditions.

DISCUSSION OF INSECT SPECIES

The insects discussed herein are presented in what is believed to be their approximate order of importance. Although nearly a hundred insect species were recorded on the soft fiber crops during the period of these observations, 1949-60) a comparatively small percentage of species are believed to present a problem to their production.

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[1]Florida Agricultural Experiment Station Journal Series, No. 1215.

[2]Associate Entomologist, University of Florida, Everglades Experiment Station, Belle Glade.

[3]Ramie, *Boehmeria nivea* L.; Kenaf, *Hibiscus cannabinus* L., Hemp, *Cannabis sativa* L.; Sunn (Sann) Hemp, *Crotalaria juncea* L.; Aramina, *Urena lobata* L.; Jute, *Corchorus olitorius* L. and *C. capsularis* L.

Hippopsis lemniscata (Fab.), a stem borer, of the family Cerambycidae occurs widely in the eastern half of the United States and is reported by Blackwelder (3) to range south to Argentina. Genung (6) has reported on the biology of this slender, brown and yellow striped long-horned beetle. Females oviposit in stems of kenaf, jute, hemp, ramie and many weeds, particularly ragweed. From 5% to 90% of canes in a commercial kenaf planting were attacked in 1951 near Belle Glade by this beetle. Infestation decreased with increasing distance from stands of weeds. Larvae fed in stems and mature larvae pupated therein. Oviposition and emergence holes contributed to lodging in the field, and to stalk breakage and fiber loss during mechanical decortication and ribboning. In addition *there is* evidence that adults transmit charcoal rot[4] which can cause death of young plants. Genung, (7) reported possible cerambycid transmission and Summers (14) discussed the stem diseases of kenaf.

Control: Disking stands of neighboring ragweed timed for three or four weeks prior to seeding fiber crops greatly reduced the beetle infestation in fiber plants. The weed control should be maintained. Disking ragweed prior to the spring emergence would seem to be a good practice. The experimenter, and possibly the entrepreneur, could use both herbicides and insecticides to advantage. An aerial application of 5% DDT dust appeared to give 100% control at about 30 pounds per acre in a commercial kenaf planting. Observations indicate that 1% parathion and 10% toxaphene dusts are also effective.

Anomis spp., family Phalaenidae: These mallow loving caterpillars attack the foliage of kenaf, *Urena*, *Sida* and wild and ornamental Malvaceae. Creighton (12) found *A. erosa* (Hbn.) to be the principle cotton leaf worm in the vicinity of Gainesville, Fla. The species *A. flava fimbriago* (Steph) and *A. illitia* Gn. have caused serious defoliation of kenaf in the Everglades. Their attacks on buds of *Urena* caused a proliferation or bushiness that is highly undesirable in bast fiber plants. Species of *Anomis* also occur in Central and South America. Larvae are green, yellowish green or tan and range up to nearly two inches long.

Control: Because of the general abundance yet lack of stand density of wild mallows, weed control would seem to offer little promise. However, insecticides have been effective in controlling these insects. An aerial application of 5% DDT dust at about 30 lbs per acre resulted in excellent control in commercial plantings in 1952. Toxaphene and parathion dusts also appeared effective in experimental plantings. Predacious pentatomids including *Podisus spp.*, *Stiretrus anchorago* Say, *Alaecorrhynchus grandis* (Dallas) and *Euthyrhynchus floridanus* L. and the reduviid, *Zelus bilobus* Say, often appear helpful in keeping infestations from getting out of control.

Prodenia eradania (Cram.) the southern armyworm, Family Phalaenidae, is also a serious defoliater of kenaf, Urena, hemp, jute and Sunn (Sann) hemp. The jute species *Corchorus olitorius* was three to four times more severely injured in replicated trials than the species *C. capsularis*. Mr. C. C. Seale noted this host selectivity at the Everglades Experiment Station. This climbing cutworm was also reported to occur widely in the Neo-tropical region by Crumb (5). The smooth larvae are richly colored with brown, black and yellow stripes and with a row of dark triangles on each side of the dorsum.

[4]*Macrophomina phaseoli* (Marlb.) Ashby = *Sclerotium bataticola* Taub.

Control: This Phalaenid can be adequately controlled by 10% DDT dust or 10% toxaphene dust at 25-35 lbs. per acre. The favorite host plant in the Everglades area is spiny amaranth[5] and frequently crop plants are not attacked until the amaranth is defoliated by the larvae which then move into the nearest vegetation. When such situations occur the insects should be destroyed before they have opportunity to migrate to crops.

Agrotis ypsilon (Rott.) and *A. subterranea* (Fab.), the black and granulate cutworms, family Phalaenidae, are frequently very injurious. They have caused heavy spot damage in commercial plantings of kenaf, and almost eliminated stands in some experimental plantings of various soft fibers. These species may occur as mixed or as distinct infestations. They appear to prefer young stands of spiny amaranth for oviposition. The black cutworm has rounded skin granules while the granulate cutworm has larger, sharper curved skin granules that tend to hold dust or earth to the skin so that they have a dirty or dusty appearance when removed from the soil. Genung (8) has discussed cultural and ecological factors affecting chemical control. It has been reported by Crumb (5) that *A. ypsilon* is almost world wide in distribution while *A. subterranea* in addition to North America occurs in the Antilles and Central and South America.

Control: Land that has been in amaranth should not be planted to any crop without a pre-planting or pre-emergence insecticide application. Best control in the Everglades area has been obtained by an application of 0.5 pound actual endrin per acre to the soil surface. Two pounds actual toxaphene per acre, similarly applied has also been effective. Under extremely heavy population conditions, two applications may be needed as 1 or 2% surviving larvae under such conditions may be a high enough figure to cause damage.

Etiella zinckenella (Treit.) the lima pod borer, family Pyralidae, has seriously damaged Sunn (Sann) hemp on sandy soils. Eggs are laid on the seed pods and sepals. Young larvae penetrate the pod and the tiny hole heals over. Larvae remain in the pod feeding on the developing seed until just before pupation thereby causing very heavy seed loss. The green or coppery to purplish red, mature larva descends to the soil and spins a net like, flat-oval cocoon that has many adhering soil particles. The lima pod borer is almost cosmopolitan and occurs widely in the Neo-tropical areas.

Control: It is suggested that all wild or cultivated species of crotalarias that have downy or hairy pods be disked two or three weeks prior to flowering of Sunn hemp. Non-pubescent crotalarias or those having a waxy bloom on the pods have not been observed as hosts of lima pod borer. Of several insecticides tested for control of this insect on lima beans, only parathion (0.15 pound per acre) gave adequate control. Poorly timed disking of wild crotalarias increased infestation in crop plants since emerging adults had no other host available Genung (9).

Utethesia bella L., the bella moth of the family Arctiidae, also attacks Sunn hemp on mineral and organic soils. Probably all species of crotalaria are attacked. The ravenous, yellowish and black banded, sparsely hairy caterpillars after consuming the contents of a pod move into another, thus even a few larvae can cause much damage. If pods are not available, they appear capable of completing their development on the foliage. The pretty pinkish to reddish, black and white marked adults are weak flyers. Various

[5] *Amaranthus spinosus* L.

species of this crotalaria-loving genus occur in the Neo-tropical region.

Control: No observations on chemical control have been made, but chlorinated hydrocarbon insecticides would probably be effective. Some benefit might be derived from maintaining control of wild Crotalarias adjacent to plantings of *C. juncea*.

Elataridae or wireworms: These insects have injured ramie, and have been reported by Thames *et al.* (15) and Berg (2), in the Everglades and elsewhere. Kenaf and doubtless the other bast fiber species also are attacked. The principle species in the Everglades are *Melanotus communis* (Gyll.), *Conoderus spp.* and *Glyphonyx Sp.* Kenaf appears particularly attractive to adult click beetles. Adults feed in considerable numbers at nectariferous glands on the main leaf vein. It is not known however, if this attraction results in a build up of wireworms on land planted in kenaf.

Control: Nothing practicable can be done to control wireworms after the crop is planted. Five pounds of actual heptachlor or aldrin are suggested per acre for wireworm control on organic soil and three pounds actual on mineral soils. The insecticide is best sprayed on the soil surface and disked into the top 4 to 6 inches of soil. Chlordane may be used where wireworms are not resistant to the chemical.

Estigmene acraea Drury, the salt marsh caterpillar, of the family Arctiidae is a common general feeder that sometimes causes serious injury to young fiber plants. These typical wooly-bear caterpillars occur in three phases: a dark, a reddish and a blonde phase although they are predominantly dark. Adults are dimorphic as the males have hind wings that are yellow on both sides while hind wings of females are white on top and yellowish below, however, the forewings of both sexes are white with darker spots. Closely related genera occur in Florida and southward.

Control: Older larvae are usually difficult to control. Good control has been obtained with Thiodan 0.5 pound actual, toxaphene at least 1.0 pound actual and phosdrin 0.5 pound actual per acre. The phytotoxic effect of thiodan and phosdrin on these plants has not been investigated. Parathion at 0.25 pound per acre also gave good control and Dylox dust appeared effective in one instance. A fungus disease identified by Dr. S. R. Dutky as *Entomopthora aulicae* has frequently decimated populations of this caterpillar

Plant bugs, of the families Pentatomidae and Pyrrocoreidae, often occur in large numbers on seed capsules of kenaf and may contribute to poor seed production. The cotton stainer, *Dysdercus suturellus* (H & S), will attack green capsules and even descend to the ground to feed on dried seed that have shattered out. The Pentatomidae, *Nezara virdula* L., *Euschistus spp.* and *Thyanta* sp. were observed to constitute a complex that heavily attacked seed heads of hemp. They probably affect vitality and viability of any seed produced, and heavy stink bug concentrations definitely affected the seed in Sunn hemp. Pods were deformed, seed were stunted, malformed or blasted and many seeds in such pods appeared to be infected by disease organisms.

Control: Adequate control of these plant bugs has been obtained with parathion and toxaphene dusts of 1 and 10% respectively. Phosdrin and Thiodan have given outstanding control of pentatomids on vegetable crops. Many pentatomids are forced to crop plants by ill-timed disking of legume cover crops such as various crotalarias, cowpeas, or sesbania. Attention to this factor can frequently obviate serious attack.

Locustidae, or short horned grasshoppers are occasionally injurious to

soft fibers. In the Everglades, species that have damaged plantings are *Schistocerca obscura* (Fab.) and *S. Americana* Drury, with the former species usually being more numerous. *S. obscura* is olive green with brown wings and a yellow dorsal stripe. *S. Americana* is tan with brown markings and a light dorsal stripe.

Control: It was observed that parathion and toxaphene dusts caused a heavy mortality of these grasshoppers.

Aphis gossypii Glov., the cotton or melon aphid, family Aphididae, is sometimes injurious to young kenaf, causing severe stunting and leaf distortion in young plants. This aphid has many hosts among the wild and cultivated plants but is very fond of members of the Malvaceae and Cucurbitaceae hence its two common names.

Control: Parathion, 1 to 2% dust has given adequate control. A number of the newer phosphatic and systemic insecticides have not been tested on these fiber plants so that the phytotoxicity aspect of them has not been investigated.

ACKNOWLEDGMENTS

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LITERATURE CITED

1. Allison, R. V. and John W. Randolph. Harvesting and Processing Ramie in Preparation for Industrial Use. Soil and Crop Sci. Soc. of Fla. Proc. 18: 306-312. 1958.
2. Berg, Ernest. Facts About Ramie. Waverly Blair Corp. Publ. Co. 40-42. 1952.
3. Blackwelder, Richard E. Checklist of the Coleopterous Insects of Mexico, Central America, the West Indies and South America. U. S. Nat. Mus. Bul. 185. 1946.
4. Creighton, John T. *Anomis erosa* (Hbn.) As An Insect Pest of Cotton. Jour. Ec. Ent. 29: 2. 279-282. 1936.
5. Crumb, S. E. The Larvae of the Phalaenidae. U. S. Dept. Agr. Tech. Bul. 1135. 323-324. 1956.
6. Genung, William G. Biology of *Hippopsis lemniscata* (Fab.) as a pest of Kenaf in Southern Florida. Unpublished Masters Thesis. Univ. of Florida. 1953.
7. Genung, William G. *Hippopsis lemniscata* (Fab.) (Coleoptera: Cerambycidae) in Relation to Kenaf Diseases. Plant Dis. Rptr. 36: 124-125. 1952.
8. Genung, William G. Ecological and Cultural Factors Affecting Chemical Control of Subterranean Cutworms in the Everglades. Florida State Hort. Soc. Proc. 163: 167-172. 1959.
9. Genung, W. G. Investigations for Control of Insects Attacking the Pods of Table Legumes. Florida State Hort. Soc. Proc. 71: 26-29. 1958.
10. Neller, J. R. Culture, Fertilizer Requirements and Fiber Yields of Ramie in the Florida Everglades. Florida Agr. Exp. Sta. Bul. 412. 1945.
11. Pate, J. B., J. F. Joyner, E. O. Gangstad and C. C. Seale. The Breeding of Improved Varieties of Kenaf, Sansevieria and Ramie in South Florida. Soil Sci. Soc. Fla. Proc. 11: 140-141. 1951.
12. Seale, Charles C. Edward O. Gangstad and J. Frank Joyner. Agronomic Studies of Ramie in the Florida Everglades. Florida Agr. Exp. Sta. Tech. Bul. 525. 1953.
13. Seale, C. C., J. F. Joyner and J. B. Pate. Agronomic Studies of Fiber Plants, Jute, Sisal, Henequen, Furcraea, Hemp and Other Miscellaneous Types. Florida Agr. Exp. Sta. Bul. 540. 1957.
14. Summers, T. E. Important Diseases Affecting Kenaf in Florida. Soil and Crop Sci. Soc. of Fla. Proc. 18: 323-326. 1958.
15. Thames, W. H., W. G. Genung and N. C. Hayslip. Univ. of Florida Agr. Exp. Sta. Ann. Rpt. 1949.
16. Wilson, F. D. and J. B. Pate. Improvement of Kenaf through Breeding and Selection. Soil and Crop Sci. Soc. of Fla. Proc. 320-322. 1958.

CONTRIBUTED PAPERS (SOILS)

W. G. Blue, Presiding

Exposed Geologic Formations of West Central Florida —An Aid to Soil Surveys

L. O. ROWLAND AND J. G. A. FISKELL[1]

INTRODUCTION

The purpose of this paper is to describe the exposed geologic formations in Citrus, Hernando, Pasco, and Sumter Counties and relate them to soil classification. This should be of special value to soil scientists, geologists, and others who are interested in soil and geology. A geologic map of the section was made and two cross sections for each county was laid out on the map from west to east and south to north and labeled A-A_1 B-B_1, C-C_1, D-D_1, E-E_1, F-F_1, G-G_1, and H-H_1 Figure 1. These cross sections were plotted from United States Geological Survey topographic sheets. About 80 soil samples were taken along these lines and at other strategic points. The samples were analyzed according to procedures in the companion paper.[2]

In the area studied there are six major geologic formations with surface exposures (Figure 1). The formations are listed and described according to age, ranging from oldest to youngest. They are: Avon Park limestone (Eocene Age), Ocala group (Eocene Age), Suwannee limestone (Oligocene Age), Tampa limestone (Miocene Age), and Alachua formation (Miocene - Pliocene Age). The least exposed of these major formations is the Avon Park limestone. No attempt was made to show it on the geologic map because of its limited area, but it was recognized and will be described. The Ocala group will be used as one unit. Each formation is capped with a blanket of sand.

Pleistocene sand (Ice Age sand) that covers the six formations ranges in thicknesses from 0 to 20 feet or more. It lies in belts parallel to the coastline and occurs in step-like terraces rising inland from the coast. The sand also extends up streams as deltas, and flood plain alluvium.

PHYSIOGRAPHY

A broad flat to very gently sloping area extends along the western side of Citrus, Hernando, and Pasco Countries. The same general slope extends across the southern part of Pasco County, north over Sumter County and back west along the Withlacoochee River. Elevation for this area ranges from 0 to about 60 feet above mean sea level. A well defined

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[1]Geologist, United States Department of Agriculture, Soil Conservation Service, Gainesville, Florida and Associate Biochemist, Department of Soils, University of Florida, respectively.

[2]J. G. A. Fiskell and L. O. Rowland Soil Chemistry of Subsoils of West Central Florida. Soil and Crop Science Society of Florida Vol. 20: 1960.

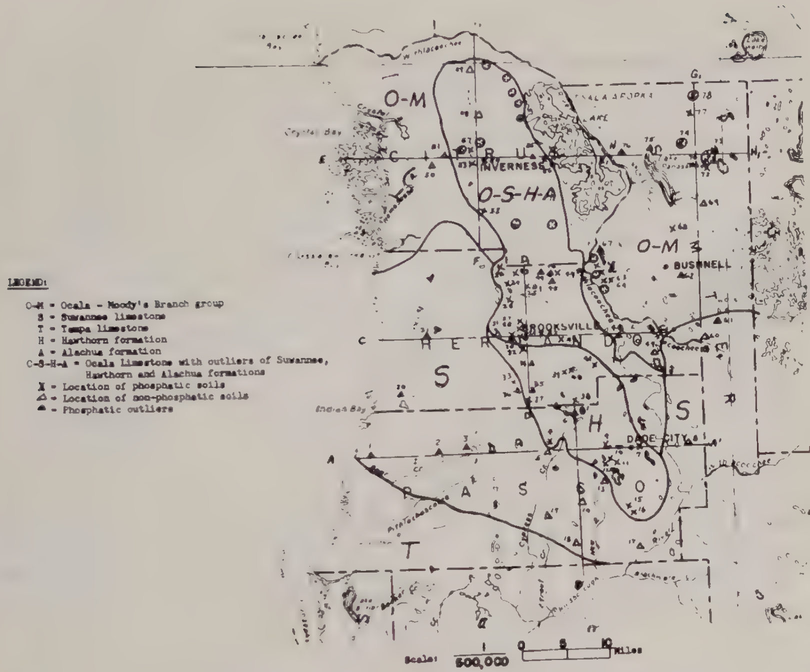

Fig. 1.

broken ridge ranging from gently sloping to rolling, extends through the central or east central part of these counties, except Sumter County, with elevation ranging from 60 to 300 feet above mean sea level.

AVON PARK LIMESTONE (EOCENE AGE)

The Avon Park limestone is a series of fragmental marine carbonate beds, with a distinct fauna, considerable amounts of peat, some lignite and other plant remains. It is mainly a cream colored chalky limestone that was probably deposited in an open sea that received little sand or clay.

Surface exposures have been found in Citrus and Levy Counties. These are the oldest rocks cropping out in Florida. The exposures are along the crest of the Ocala uplift where the fold has been breached by marine planation and stream excavation. Several small outcrops are present along the Withlacoochee River valley at the Florida Power Corporation dam and in several other areas along the south side of the lake. Since the outcrops are located on the general crest of the Ocala uplift, the exposures of Avon Park limestone extend along stream valleys on opposite flanks of the Ocala fold. The Avon Park limestone is separated from older and younger beds by erosional unconformities. The Moody's Branch marl lies immediately above it while the Lake City limestone lies just beneath it.

OCALA GROUP LIMESTONES (EOCENE AGE)

Color of the unexposed Ocala limestone ranges from white through cream color to yellow. The exposed portions take on a light gray to dark gray color. There is little variation in texture because most of the limestone is granular; however, parts of it have been changed into hard, compact rock by deposition of travertine and silica in its voids. In most places the formation consists of a loosely coherent mass of fossilized organisms like the foraminifer, bryozoan, echinoid, mollusk, and other marine organisms. The Ocala is remarkably uniform in chemical composition and in physical character. In some places it contains less than one percent of impurities and over ninety nine percent carbonate of lime. This mass is so porous that water can percolate freely through it.

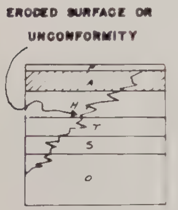

FIG. 2A

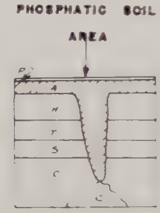

FIG. 2B

FIG. 2C

FIG. 2D

FIG. 2E

The free circulation of water over and through the Ocala group has caused the erosion of the rock. Many cone-shaped solution cavities, most of them filled with sand, clay and even bones of land animals, lead downward from the surface to connect with ramifying underground caverns, fissures and passages. See Figure 2-D. The solution of the limestone at many places has been accompanied by silification resulting in a flint-like rock. This rock may appear as a sheet ranging in thickness from less than one inch to a foot or more or it may occur as an irregular mass; however, in either case it may be a psuedomorphous replacement of shells or granules. Some of these psuedomorphs preserve with great fidelity the exact original form or pattern of the shell. Many so called Ocala limestone boulders with well preserved casts are strewn over areas that are strongly acid both in the soil and in the boulders because practically all of the carbonates have been removed. It is likely that the carbonates have been removed by solution and weathering during 20 million years duration for the Eocene Age (Table 1).

Thickness of the Ocala group is difficult to determine because the top is an eroded, uneven surface and the bottom has not definitely been identified (See Figure 2-A). The presence or absence of a formation in the

Table I, GEOLOGIC FORMATIONS IN CITRUS, HERNANDO, PASCO, AND SUMTER COUNTIES, FLORIDA

	Age Years (Estimated)	Formation	Major Physical Properties	Estimated Rainfall In Millions of Feet (Depth) For Each Age
	Recent Pleistocene 1 million years	Estuarine and marine terrace deposits	Principally sands	4
	Pliocene 10 million years	Alachua formation	Sands, clays and phosphate	40
	Miocene 15 million years	Hawthorn formation	Interbedded sand, clay, marl, limestone and phosphate	60
Cenozoic Era		Tampa limestone	Limestone and sandy limestone, in places dolomitic. 15 - 41% $CaCO_3$ 10 - 35% $MgCO_3$ 71 - 20% S_1O_2	
	Oligocene 10 million years	Suwannee limestone	Hard, soft, and granular limestone. 91-97% $CaCO_3$ 9- 3% S_1O_2	40
	Eocene 20 million years	Ocala limestone	Porous limestone 98 - 99% $CaCO_3$ 2 - 1% impurities	80

area studied is of more importance than the thickness so long as the formation has a direct influence upon the soils. For this reason the thickness of the major formations are not given.

SUWANNEE LIMESTONE

The Suwannee limestone is commonly hard and resonant ranging in color from yellow or cream to white with a pinkish tinge. Small solution holes filled with green clay are abundant. In some places a dark-reddish clay is resting directly upon the limestone and it is usually acid or neutral. (See Table 2 Sample Numbers 23 and 29). Where the Suwannee limestone is unaltered, it consists of a soft granular mass of limey fragments, many of them of organic origin. Some of the surface exposures and the brown to tan residual boulders are like those of the Ocala limestone in that practically all of the lime has been leached from the original mass, leaving a porous or massive flint that is recognizable as Suwannee boulders by the presence of well preserved molds of the key or common Suwannee echinoid, *Cassidulus gouldii*. Some of these boulders are in a pasture on the south side of U. S. Highway 98 in Sec. 13, 8½ miles northwest of Brooksville, Florida.

The Suwanne limestone in Hernando County is very variable. There are patches or outliers of hard and soft rock that are irregularly distributed along the center of Hernando County as well as in the central part of Citrus and to some extent in the northeastern part of Pasco County. (See Figure 1, Symbol O-S-H-A). These outliers show no relation to the true bedding planes.

The unaltered Suwannee limestone contains about 91 to 97 percent calcium carbonate ($CaCO_3$) and the chief impurity is silica (SiO_2). A large part of the Suwannee limestone is composed of marine mollusks and faraminifera. The abundance of the mollusks and faraminifera indicates that the Suwannee limestone was formed in relatively quiet, warm, shallow to moderately deep, marine waters. The deposition of the Suwannee limestone seemed to have occurred at the close of the Oligocene

Age as indicated by the drastic and noticeable changes of succeeding sediments.

TAMPA LIMESTONE (MIOCENE AGE)

The Tampa limestone marks the beginning of the Miocene Age which brought a distinct change in sedimentation, both in environment and source area. Up until the close of the Oligocene Age, little sand and clay had been supplied to the deposits because the land area or source material for supplying sand and clay was so far away (about 200 miles north of the area being studied). Then too, the depth of the water could have prevented clastics from reaching the area. Beds of calcareous or dolomitic clayey sand and clay mark the beginning of deposition of the Tampa limestone. It seems likely that throughout the early Miocene Age, islands, estuaries and fresh water lakes were prevalent because the formation contains land, fresh water and marine fauna ranging from the base of the formation to near the top.

It is apparent that the environment under which the Tampa limestone was laid down varied greatly. The water was shallow, and islands and lagoons were common. A varied sea floor and the increased activity of ocean currents were probably responsible for the localization of the clastic materials. Almost pure limestone accumulated in some fresh water lakes, while clastic sediments were deposited in other areas. These varied conditions make the time—stratigraphic sequence very complex in the Tampa limestone.

HAWTHORN FORMATION (MIOCENE AGE)

The Hawthorn sediments were deposited under continental and deltaic environments by a transgressing sea that flooded and eroded the land surface. The uneven thickness of the formation is attributed to the deltaic and pro-deltaic nature of the sediments that fan out from the general center of the Hawthorn delta, and also from the erosional uncomformities at its base and top.

The formation as noted in this study contains some phosphatic sand and clay, some sandy-marly limestone, approximately 10 percent quartz, and a high percentage of greenish-gray massive or blocky montmorillonite clay. The chemical and physical properties of the clay suggest that it may be bentonitic but no glass shards or other types of volcanic ash were detected.

The clay is very similar to other clays which occur elsewhere in the Hawthorn formation, some of which appears to have replaced limestone lost through weathering.

An intermediate product of disintegration is gray or white, very light porous sandstone from which most of the lime and a high percentage of the phosphate have been dissolved, leaving smooth rounded blebs or pebbles of iron oxide in place of the more concentrated phosphatic grains. In spite of the long weathering of these rounded pebbles, many contain as much as 5.720 per cent P_2O_5. (See Table 2 Sample No. 66). This is about twenty-five times more P_2O_5 than is needed to classify a soil as phosphatic, assuming the breaking point between a phosphatic and non-phosphatic soil to be 0.23 per cent P_2O_5 for soils in Florida.

ALACHUA FORMATION (MIOCENE–PLIOCENE AGE)

The Alachua formation is probably the most complex formation in Florida. It is terrestrial, in part possibly lacustrine and fluviatile, and is a mixture of interbedded irregular deposits of clay, sand and sandy clay of the most diverse characteristics. The formation occupies irregularities in the limestone bedrock and covers it to unknown depths in some places. (See Figure 2-B). These irregularities may be in the form of solution pits, sinks, fissures, and old filled valleys. They seem to be arranged along a northwest-southeast direction that more or less parallel the crest of the Ocala uplift and the fracturing that is thought to be associated with the uplift. There are several such outliers of Alachua phosphatic deposits northwest of Inverness in Citrus County. (See Figure 1).

There seems to be no consistent lithologies or sequences of beds; however, detailed studies over the entire formation may prove that there are regular succession of beds, because portions of the formation are faintly stratified, crossbedded, and poorly indurated in a phosphate-clay mineral matrix. The clay lenses in the Alachua formation are usually montmorillonite clay in light pastel shades of blue and green, with plastic consistance. These lenses occasionally contain a few pebbles of phosphate.

The phosphate in the Alachua formation may occur as boulders, clastics ranging from grain size pebbles to colloidal clay, or as laminated-phosphate rock in replacements of limestone.

Perhaps there are no fossils that can be definitely associated with the Alachua formation as a key fossil, but there are many and various kinds of fossils in the deposits. The age of fossils in the Alachua formation ranges from upper Eocene to Pleistocene. Examples of these are: *Lepidocyclina* of the Ocala group, *Cassidulus gouldii* of the Suwannee limestone, three-toed horse, camel, rhinoceros, mastodon, deer, and alligator of the Miocene-Pliocene-Pleistocene. These fossils and animal remains were plucked from the sides and roof of the respective formations during a collapse of the underlying deposits, therefore fossils from the Pleistocene or Pliocene may be resting directly upon or in older deposits like the Eocene.

OCALA UPLIFT

The Ocala uplift accounts for much of the complexity in patterns of soils and in geology in Citrus, Hernando, Pasco and Sumter Counties, as well as in some of the adjoining counties. This is a structural high which

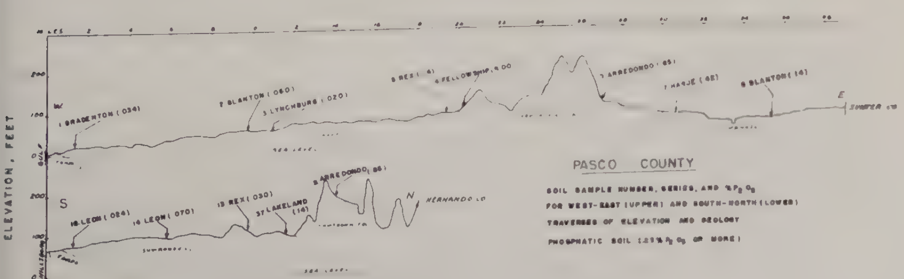

FIG 3

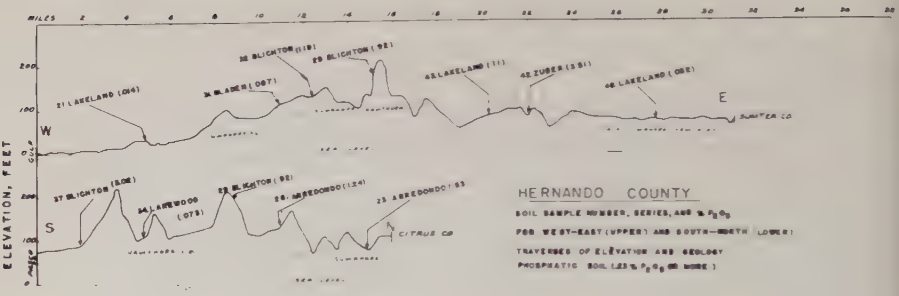

FIG 4

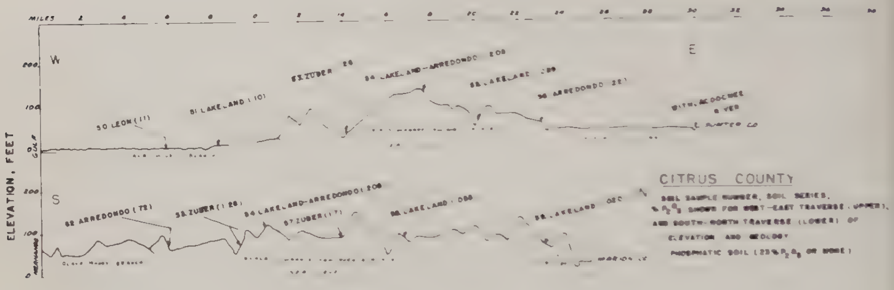

FIG 5

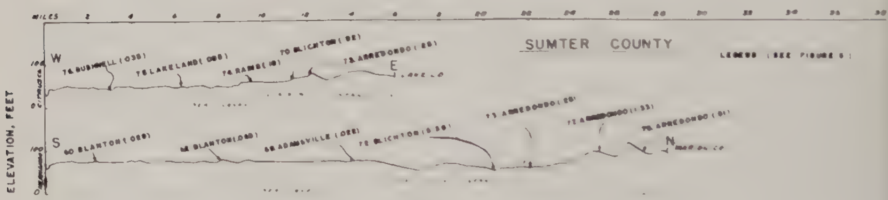

FIG 6

probably had its beginning during lower Miocene epoch, approximately 25 million years ago. The arch roughly extends from about the center of Polk County northwesterly to Madison and Hamilton Counties, a distance of approximately 200 miles. The uplift is parabolic with an average width of approximately 60 miles. Figure 2-E is a schematic drawing of a portion of the uplift in the area being studied. How much displacement took place during the arching of the Ocala is not known but it must have been several hundred feet.

Many faults, fractures, grabens and joints have been found associated with the Ocala uplift. Perhaps the most outstanding one is the Long Pond Fault which has an almost vertical displacement of 160 feet. This fault crosses the Citrus-Marion County line near where Blue Spring flows into the Withlacoochee River from Marion County. Another major fault is the Inverness Fault with about 70 feet of displacement. It extends roughly from near Floral City to about the southeast corner of Levy County.

The regional fractures all seem to parallel the axis of the uplift and locate the crest. The fractures trend northwest-southeast. Many sections

of the fractures and sink-like areas along lines of weakness have been filled with clastic sediments classified as phosphatic and belonging to the Alachua formation. Several such pockets exist today in Citrus County, northwest of Inverness, around Lecanto, west of Floral City, and in Sumter County near Wildwood, Figure 1.

The area marked as O-S-H-A (Ocala, Suwannee, Hawthorn and Alachua) on the map owes it complexities to the Ocala uplift, forces that accompanied it, and the erosional cycles. Several attempts were made to map the geologic outcrops in this area, but the outcrops were so badly broken and mixed that it was thought best to map the area as a "mixed-geologic phase." There are exposures of the Ocala group, Suwannee limestone and Hawthorn formation thrust together in a very irregular fashion. Parts of the Alachua formation were incorporated into this shattered and mixed condition to depths well over a hundred feet in some places. Erosional cycles removed and scattered much of these different formations so that the surface today ranges from flat to hilly.

It is believed the so-called Alachua-phosphatic blanket covered most or all of the O-S-H-A area at one time. Erosion scattered, diluted and even removed all but traces of phosphate in some places. This is one reason why phosphatic and non-phosphatic soils have such an irregular pattern in this area. The only known commercial deposits of phosphate in this section are in the sinks or fissure-like depressions. Figure 2, C and D.

The phosphatic outliers in Sumter County near the Withlacoochee River and around Wildwood are thought to be different from the outliers in Citrus County in that they represent the bottom or almost the last traces of former phosphatic outliers. The bottom or general surface of these outliers correspond roughly to the bottom of the phosphatic pits northwest of Inverness in Citrus County that are being mined or have been mined.

According to the geologic formations in the area, two contained phosphate, Hawthorn and Alachua formations, and four did not, Avon Park, Ocala, Suwannee and Tampa limestone. Some of the phosphate has been transported through solution, erosion, and the collapse of the underlying sinks, fissures, and fractures to the non-phosphatic formations.

Cross section A-A_1, Pasco County (Figure 3) shows the arrangement of phosphatic and non-phosphatic soils as they relate to the non-phosphatic Suwannee limestone and the phosphatic Hawthorn formation. There are eight sample sites along the cross section. Five are non-phospatic, and three are phosphatic. The non-phosphatic soils (Site, Name, Number and percent P_2O_5) are 1. Bradenton .034% P_2O_5, 2. Blanton .60% P_2O_5, 3. Lynchburg .020% P_2O_5, 5. Rex .14% P_2O_5, and 8. Blanton .14% P_2O_5. These are all above the non-phosphatic Suwannee limestone. The phosphatic soils (Site number, Name, and percent P_2O_5 are 4. Fellowship 8.00% P_2O_5, 9. Arredondo .85% P_2O_5, and 7. Hague .42% P_2O_5. These are all directly above the phosphatic-Hawthorn formation except number 7 - Hague. This is understandable because the site is near the base of a long Hawthorn formation slope, then too, it is also near the Hawthorn-Suwannee geologic contact.

All the other cross sections show a similar relationship between phosphatic and non-phosphatic soils as they relate to phosphatic and non-phosphatic-geologic formations. The same is true for the other soil sites taken throughout the four counties. The irregularities can be explained by former erosion, solution, or the collapse of underlying strata.

CONCLUSION

A geologic map is an essential tool in the hands of the soil scientist especially where the geology is badly mixed. Even where the formations are not breached or disturbed, a geologic map will tell many things about the physical conditions of an era. If the characteristics of a geologic formation are known, much can be learned as to the kind of soils to be expected. See Figure 1 and Table 2. For example: Because the Ocala group was about 99 percent $CaCO_3$, you should expect to find acid soils even close to the limerock. The carbonates leach more readily from this kind of formation than they do from a limestone that contains a high percentage of iron, aluminum, insolubles and other impurities as found in Hawthorn limestone. The exception is where the water table, perched or piezometric, is standing or has stood for a long time near the surface. In this case, sweet soils are likely to exist because the carbonates have not had a chance to be transported from the local area. (See Table 2 sample numbers 1 and 49). Number 1—Bradenton has a pH of 7.9, number 49—Hernando has a pH of 8.1.

Formations with phosphate usually give rise to phosphatic soils. The Hawthorn and Alachua formations contain phosphate in the area studied, therefore, by knowing the boundaries of these formations, it is possible to predict areas of phosphatic soils.

Another example of how geology can help solve a soils problem is shown in the analysis of what appeared to be the same kind of fragments and pebbles as they were found and collected in the field. One sample came from Tampa limestone with .002% P_2O_5 and the other from the Hawthorn formation with 5.7% P_2O_5. In each case the ground surface and general appearance appeared to be phosphatic. The sample from the Tampa limestone had a trace of phosphate, while that from the Hawthorn formation was strongly phosphatic.

TABLE 2.—LOCATION, TOTAL PHOSPHATE, PH, AND CALCIUM CONTENT OF SOILS SAMPLED IN WEST CENTRAL FLORIDA.

Sample No.	Soil Series and Location	Total P_2O_5	pH in H_2O	Calcium Exchange-able	Calcium Total*
		Percent		PPM	Percent
	PASCO COUNTY				
1	Bradenton (disturbed) 3-6″ above marl 4 Mi. S. Hudson Fla. 55	.073	7.9	780	VH
2	Blanton, 24-36″ 4 Mi. NW Gowers Corner	.060	4.8	11	.14
3	Lynchburg, 24-36″ 3 Mi. N. Gowers Corner U.S. 41	.020	6.3	50	
4	Fellowship, 18-24″ 1½ Mi. NE Darby	8.00	5.1	483	.049

*VH denotes free lime present; VL=Less than .01 percent.

TABLE 2.—(Continued)

Sample No.	Soil Series and Location	Total P_2O_5	pH in H_2O	Calcium Exchange-able	Calcium Total*
		Percent		PPM	Percent
5	Rex, 6-12″ 1 Mi. N. Darby	0.14	5.4	218	.033
6	Arredondo, 24-36″	.025	5.9	7	.15
7	Hague, 20-30″ 1½ Mi. NE Dade City	.423	5.5	110	.11
8	Blanton, 20-30″ 5 Mi. E. Dade City	.140	6.1	7	.00
9	Gilead, 20-30″ 3 Mi. W. Dade City	.078	4.8	12	.62
10	Arredondo, 39-42″ At San Antonio	.85	5.1	280	.03
11	Arredondo, 24-36″ At San Antonio	.30	4.9	48	.00
12	Arredondo, 20-30″ ¼ Mi. NW Lake Pasedena Fla. 579	.89	4.3	74	VL
13	Rex, 24-36″ 2 Mi. S. San Antonio Fla. 577	.140	5.0	84	VL
14	Leon, 20-30″ 2½ Mi. NE Wesley Chapel Fla. 577	.070	5.9	10	.12
15	Gainesville, 60-66″ 1½ Mi. NW Zephyrhill	1.13	5.3	485	.088
16	Hague, 36-48″ 1½ Mi. NW Zephyrhill	3.20	5.3	650	.105
17	Bushnell, 20-24″ 3 Mi. S. Zephyrhill	.08	5.1	590	.079
18	Leon, 24-30″ 3 Mi. S. Wesley Chapel	.024	5.1	10	.05
19	Leon, 24-36″ 2½ Mi. W. Wesley Chapel Fla. 54	.030	5.2	26	VL
	HERNANDO COUNTY				
20	Lakeland, 36-48″ 1½ Mi. N. Co. line U.S. 19	.034	6.5	26	VL
21	Lakeland, 24-36″ 3 Mi. N. Weekiwachee Spgs.	.014	6.5	18	.25
22	Hague, 12-18″ 1½ Mi. S. Co. line Fla. 491	.29	6.0	970	.132
23	Arredondo (Clay 6″ above Suwannee lime) ½ Mi. E. Stafford Fla. 476	.53	6.6	740	.05
24	Arredondo, 18-20″ ½ Mi. SW Stafford U.S. 98	.23	5.0	320	.113

*VH denotes free lime present; VL=Less than .01 percent.

TABLE 2.—(Continued)

Sample No.	Soil Series and Location	Total P_2O_5	pH in H_2O	Calcium Exchange-able	Calcium Total*
		Percent		PPM	Percent
25	Blichton, 20-30" 4½ Mi. N. Brooksville Fla. 476	1.74	5.2	1,110	.20
26	Blichton, 18-24" 4 Mi. N. Spring Hill Fla. 491	8.55	5.6	280	.03
27	Arredondo, 24-30" 2 Mi. N. Brooksville U. S. 98	1.19	4.9	120	.07
28	Arredondo, 60-66" 2 Mi. N. Brooksville U.S. 98	1.24	4.9	134	.044
29	Blichton, 10-12" (6" above Tampa-Suwannee limestone) 1 Mi. N. Brooksville	.92	5.0	160	VL
30	Blichton, 12-36" 1 Mi. NW Brooksville	1.01	4.5	52	VL
31	Bladen, 24-36" ½ Mi. Spring Hill Fla. 491	.087	4.8	12	.16
32	Blichton, 48-54" In Brooksville at R.R.	1.19	5.4	270	VL
33	Blichton 20-24" 5 Mi. S. Brooksville U. S. 41	.46	5.0	400	.04
34	Lakewood, 24-36" 4 Mi. S. Brooksville Fla. 581	.073	5.2	90	VL
35	Blanton, 24-36" 1 Mi. SE Powell Station	.092	5.1	74	VL
36	Blanton, 24-30" 1 Mi. SE Powell Station	.110	5.4	80	VL
37	Blichton, 22-24" 2 Mi. SE Powell Station	3.02	4.9	160	.04
38	Arredondo, 36-42" ¾ Mi. N. Co. line Fla. 41	.28	4.9	30	.00
39	Arredondo, 36-42" 1½ Mi. N. Spring Lake Fla. 41	.92	4.8	32	.00
40	Arredondo, 36-48" 1½ Mi. N. Spring Lake	.69	6.3	30	.00
41	Ft. Mead, 30-36" 8 Mi. E. Brooksville U.S. 98	3.22	5.7	36	.00
42	Zuber, 24-48" N. side of Munden Hill	3.51	5.1	180	.15
43	Lakeland, 24-36" 3½ Mi. E. Brooksville on R.R.	.113	5.1	70	.10
44	Arredondo, 12-15" 1½ Mi. S. Co. line U.S. 41	.098	5.5	148	.03

*VH denotes free lime present; VL=Less than .01 percent.

TABLE 2.—(Continued)

Sample No.	Soil Series and Location	Total P_2O_5	pH in H_2O	Calcium Exchange-able	Calcium Total*
		Percent		PPM	Percent
45	Fellowship on Suwannee Limestone 2 Mi. S. Co. line Fla. 476	.050	8.5		33.40
46	Suwannee (Limestone) 2 Mi. S. Co. line Fla. 476	.053	7.1		34.80
47	Fellowship, 6-20″ 2 Mi. S. Co. line Fla. 476	.348	5.4	590	.14
48	Lakeland, 24-40″ 2 Mi. S. Croom	.052	5.9	40	.14
49	Hernando 2½ Mi. N. Co. line U.S. 301	.038	8.1	820	7.50
	CITRUS COUNTY				
50	Leon, 20-30″ 4 Mi. SW Crystal River	.110	6.1	70	.13
51	Lakeland, 24-36″ 3½ Mi. S. Crystal River	.101	5.9	120	.15
52	Arredondo, 24-40″ 4½ Mi. SE Lecanto Fla. 491	.723	5.0	20	.15
53	Zuber, 24-30″ 1 Mi. S. Lecanto Fla. 491	1.26	5.3	372	.097
54	Lakeland, 24-36″ 2 Mi. E. Lecanto Fla. 44	.208	5.1	18	.14
55	Lakeland, 24-36″ 1 Mi. W. Inverness	.089	5.6	11	.19
56	Lakeland NW Section of Inverness	.218	5.8	25	.12
57	Zuber, 18-20″ 3 Mi. N. Lecanto Fla. 491	1.72	5.7	1,360	.217
58	Lakeland, 26-40″ 2 Mi. S. Holder Fla. 491	.055	5.9	52	.19
59	Lakeland, 24-36″ 3½ Mi. NW Holder Fla. 45	.020	5.9	25	.05
	SUMTER COUNTY				
60	Blanton, 20-36″ 1 Mi. S. Tarrytown	.029	5.5	12	.15
61	Arredondo, 20-36″ At. Linden	1.03	5.7	180	.09
62	Blanton, 24-40″ Bevilles Corner	.065	5.9	55	.09
63	Arredondo, 20-24″ ½ Mi. E. Nobleton Fla. 476	4.800	5.9	95	.35
64	Arredondo ½ Mi. E. Nobleton Fla. 476	0.583	5.9	280	.22
65	Kanapaha, 30-36″ 1½ Mi. NE Nobleton Fla. 575	0.835	6.5	90	.07

*VH denotes free lime present; VL=Less than .01 percent.

TABLE 2.— (Continued)

Sample No.	Soil Series and Location	Total P_2O_5	pH in H_2O	Calcium Exchange-able	Calcium Total*
		Percent		PPM	Percent
66	Arredondo, phosphatic pebbles 1½ Mi. NE Nobleton Fla. 575	5.720	5.4		.16
67	Panasoffkee, 20-30" 3 Mi. NE Nobleton Fla. 575	0.160	4.8	12	.03
68	Adamsville, 36-42" 2½ Mi. N. Bushnell Fla. 475	.32	5.7	44	.00
69	Adamsville, 24-36" At Sumterville	.022	5.9	60	.13
70	Blichton, 20-30" 2 Mi. SE Wildwood	.915	5.5	100	.03
71	Blichton, 20-30" 2 Mi. SE Wildwood	1.310	5.0	300	.61
72	Blichton 2 Mi. SE Wildwood	5.38	5.9	1,280	.70
73	Arredondo, 28-36" 1 Mi. SE Wildwood	.252	5.5	80	.04
74	Raines, 24-28" 1 Mi. W. Wildwood Fla. 44	.183	4.8	210	.07
75	Lakeland, 24-36" 5 Mi. W. Wildwood Fla. 44	.085	5.8	40	.13
76	Bushnell, 16-20" 8 Mi. W. Wildwood Fla. 44	.217	5.1	610	.13
77	Arredondo, 30-42" 1 Mi. S. Oxford	1.33	6.9	580	.06
78	Arredondo, 30-42" 1½ Mi. N. Oxford	0.51	5.9	150	.00

TABLE 3.—GEOLOGIC FORMATIONS AND LOCATION OF PHOSPHATIC AND NON-PHOSPHATIC SITES.

Geologic Formation	Phosphatic Sites* No.	Phosphatic Sites* Location**	Non-phosphatic Sites* No.	Non-phosphatic Sites* Location**	Total Sites
O-S-H-A	17	22, 23, 24, 25, 26, 27, 28, 29, 30, 43, 44, 47 52, 53, 54, 56, 57	7	31, 44, 45, 46 55, 58, 59	24
Hawthorn formation	14	4, 7, 9, 10, 11, 12, 15, 16, 32, 37, 38, 39, 40, 41	3	6, 34, 35	17
Tampa limestone	0	0	0	0	0
Suwannee limestone	1	33	15	1, 2, 3, 5, 8, 13, 14, 17, 18, 19, 20, 21, 36, 60, 61	16

OM Ocala-Moody's Branch	12	63, 64, 65, 66, 68, 70, 71, 72, 73, 74, 77, 78	9	48, 49, 50, 51, 62, 67, 69, 75, 76	21
Totals	44		34		78

*See Table 2 .23 percent P_2O_5 or greater.

**See Figure 1.

LITERATURE CITED

1. Black, A. P., Eugene Brown and J. M. Pearce. 1953. Salt Water Intrusion in Florida; Water Survey & Research Paper No. 9: 38 pp.; State Board of Conservation.
2. Cooke, C. Wythe. 1954. Geology of Florida, Florida State Geological Survey Bulletin, 29: 339 pp.
3. Cooke, C. W. and Mossom, S. 1927-28. Geology of Florida, Florida Geology Survey, 20th Annual Report: pp. 30-227.
4. Pirkle, E. C. 1956. The Hawthorn and Alachua Formations of Alachua County Florida; Quart, Jour. Florida Acad. Sci., 19:4, 197-240.
5. Southeastern Geological Society, Ninth Field Trip Guidebook, Late Cenozoic Stratigraphy and Sedimentation of Central Florida, 134 pp.
6. Vernon, Robert O. 1951. Geology of Citrus & Levy Counties, Florida State Geological Survey Bulletin 23: 256 pp.

Soil Chemistry of Subsoils of West Central Florida

J. G. A. FISKELL AND L. O. ROWLAND[1]

INTRODUCTION

The weathering of soils in the ridge section of Florida has probably proceeded for a million years or more. Since many of these soils were formed from phosphatic deposits of the Alachua and Hawthorn Formations and since both fresh, calcareous marine and geologic limestone residues were usually present, an excellent opportunity is afforded in this area to study both the end-products of weathering of the calcareous soils and of calcium phosphate. In another paper (6), the authors pointed out the close relationship of phosphatic soils to the area of underlying Alachua Formation and to erosion or collapse of this material into the primarily non-phosphatic areas. The information in both papers is intended to provide more and necessary data for soil classification and management.

METHODS AND MATERIALS

The soil samples were taken from the subsoil of several soil series representative of the West Central Florida area within Citrus, Hernando, Pasco and Sumter Counties. These samples were air-dried sieved, and then analysed by the following methods:

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Soil Acidity. A 50-g. sample of the soil was mixed with 100 ml. of distilled water and stirred frequently for one hour. The pH was read using a Bechman G pH-meter with $\pm.05$ pH accuracy. Exactly 0.75 g. of KCl was added to make 0.1N solution. After stirring well the pH was read again. The solution was filtered through double No. 5 or No. 32 Whatman filter papers. A 50 ml. aliquot was titrated with 0.02 N NaOH to pH 7.0 using phenol red indicator to give total titratable acidity. One g. of NaF was added, the solution was stirred and back-titrated with 0.02 N HCL to pH 6.5. This titration of the OH^- released by the complexing of Al from hydroxide formed by the hydrolysis of Al-salts was calculated as milliequivalents of Al (8). A separate aliquot of the filtrate was also analysed for Al by the method of Yuan and Fiskell (9). The actual H^+ not present from Al^{+++} hydrolysis was calculated from the difference of the two titrations after subtraction of the small blank for the NaF which is slightly alkaline.

Exchangeable cations. The exchangeable cations, Ca^{++}, Mg^{++}, K^+ and Na^+ were determined in a separate sample after extraction of 2 to 10 g. of soil with 75 ml. of N NH_4Ac, pH 4.8. The hydrogen-oxygen flame was used for Ca, K and Na determination using the Bechman DU spectrophotometer. The thiazole-yellow and polyacrylate method of Mehlich (4) was used for Mg.

Acid digestion of the soil. A 1-g. sample was taken and digested repeatedly with aqua regia and finally taken to near dryness several times with concentrated HCl. The sample was diluted to 100 ml. with 0.2 N HCl. Total P_2O_5 was determined on a suitable aliquot by the procedure of Chang and Jackson for iron phosphate (1). After removal of Al, Fe and PO_4 by precipitation at pH 5.8-6.0, the sample was filtered and the calcium was precipitated twice as the oxalate and determined by permanganate titration of the oxalate. Where insufficient Ca was present for the titration, as above, Ca was determined by the flame photometer using standards made with the same concentration of NH_4 and Cl as the samples. Aluminum was determined on a separate aliquot by the modified aluminum method (9). Iron was determined using the citrate-orthophenanthroline procedure of Sandell (7). Potassium was also run on many samples using the flame photometer.

Exchange capacity. Depending on the texture, 2 or 10 g. of soil was shaken with N NH_4Ac at pH 7.0 and centrifuged. This was repeated. Two ethanol and methanol rinses were used to displace excess NH_4Ac. Following the displacement of the NH_4^+ from the soil with normal KCl acidified to pH 3 (to remove interlayer or fixed NH_4+), the NH_3 was distilled into boric acid. The boric acid solution was titrated back to its original pH by 0.1 N NaOH and the exchange capacity calculated from the titration.

Clay dispersal. Several soil samples were shaken repeatedly with water followed by centrifuging at 1800 rpm until clay was suspended. About 10 to 25% of the clay was removed in this manner. This clay fraction was used in an attempt to identify phosphate forms without much risk of dissolving or transforming these compounds. In another sample, the clay fraction was dispersed using 0.1 N NaOH and this was termed the total clay fraction. This clay was finally weighed after alcohol rinses and

drying at 60°C. For X-ray diffraction, the clay was Mg-saturated, subjected to ethylene glycol solvation and orientated on petrographic slides. In the X-ray-diffraction, the settings and the interpretations were made as prevously descrbed (2).

Fractionation of soil phosphorus. The method of Chang and Jackson (1) was used to fractionate the soil phosphorus. A 10 g. sample was used for sands and a 2g. sample for the finer textured soils. The reductant soluble iron phosphate was extracted with $Na_2S_2O_4$ and 0.3M sodium citrate as in the above method except that temperatures were controlled by a hot-plate. The values found for phosphate using the oxidation by H_2O_2 were found to be similar to axidation by aqua regia. The soil was extracted finally with O. in HC_1 which gives the occluded aluminum-iron phosphate (barrandite-like) according to the method.

The field sample numbers and soil series are consistent between this and the companion paper (6) and the data are grouped into several catagories.

RESULTS AND DISCUSSION

Particle size distribution. The textures of the soils ranged from sands to sandy clays. Despite the wide range between series in sand and clay content, the silt content was only in the range 0.5 to 5.3%. The silt content was very much lower than was found in the soil series from West Florida (2). Data previously reported by Gammon *et al.* (3) also showed soils of similar texture were lower in silt from Central or Southern Florida than from the northern or western counties. This would indicate that the parent or deposited material was low in silt and possibly that sand, silt and clay were deposited by different marine actions. The color of the sands from different parts of the counties studied also varied greatly, with that of Leon being the whitest. The data on particle size distribution are reported in Tables 1, 2, 3 and 4.

Clay mineralogy and phosphate content. The clay mineralogy of the soil series is discussed for each county. The phosphate-content of each sample was related to the underlying geology in the paper by Rowland and Fiskell (6). The soil series sampled in Pasco county, Table 1, have rather similar crystalline minerals, namely; vermiculite, kaolinite, quartz and hydrous mica. The sample of Fellowship, No. 5, contained 8% P_2O_5 or approximately 18% as a phosphate compound and yet a pattern for a crystalline phosphatic mineral was not present in the water-dispersed clay. Montmorillonite was the dominant mineral and accounted for part of the highly expanding properties of this clay. However, Samples No. 10, 11, 15, 7 and 16 were also expanding clays without montmorillonite or vermiculite in sufficient amounts to be detectable by X ray diffraction. These soils are also phosphatic and it is likely that the phosphatic compounds are highly hydrated forming a somewhat random network of tetrahedral structures rather than fixed planes found in clay minerals. Such a structure would be essentially amorphous to X-rays because the randomness as well as the porosity would not favor diffraction patterns being formed. Amorphous aluminum hydrates and hydrated iron oxides in soils also do not give X-ray patterns.

Many more of the expanding clays were found in soil series from Her-

TABLE 1.—THE SAND, SILT, CLAY AND P_2O_5 CONTENT, AND MINERALOGY OF SOIL SERIES SAMPLED IN PASCO COUNTY

Soil No.	Soil Series	Depth Sampled	Particle Size Distribution			Total P_2O_5	Clay Mineralogy from X-ray-Diffraction Pattern[1]	
			Sand	Silt	Clay			
		inches	%	%	%	%	H_2O-Dispersed	Whole Clay
6	Arredondo	24-36	96-4	1.3	2.0	0.025		K_1V_3
10	Arredondo	39-42	53.9	3.8	42.0	.85	K_1Q_3A	
11	Arredondo	24-30	90.4	2.9	4.5	.30	K_1A	
2	Blanton	24-36	97.3	.8	1.7	.06		$V_2K_2Q_2$
8	Blanton	20-30	96.5	.8	2.4	.14		V_1K_1
5	Fellowship	18-24	38.8	3.7	55.3	8.00	$M_1HM_2K_2$	
15	Gainesville	60-66	80.0	5.3	13.2	1.13	Amorphous	
9	Gilead	20-30	63.3	1.3	34.8	.08		K_1
7	Hague	20-30	82.2	3.4	14.1	.42		$V_2K_2Q_3W_3$
16	Hague	36-48	63.6	4.1	31.2	3.20	$K_1V_2HM_2A$	
14	Leon	20-30	96.5	.5	1.0	.07		$V_2K_2HM_3Q_3$
18	Leon	24-30	93.7	2.3	1.1	.02		$V_2K_2Q_2$
3	Lynchburg	24-36	96.9	.7	1.6	.02		$Q_1K_3V_3$
4	Rex	6-12	42.0	2.7	57.0	.14	$Q_1K_2HM_2$	K_1HM_1
13	Rex	24-36				.14		

[1]Code for mineralogical data: A=amorphous, K=Kaolinite, Gi=gibbsite, HM=hydrous mica, M=montmorillonite, Q=quartz, V=Vermiculite, W=wavellite and $_1$=40% or greater, $_2$=10 to 40% and $_3$=less than 10% present.

nando County. From the mineralogy shown in Table 2, it was concluded that the phosphates dominated this property rather than expanding layer lattice minerals. The definite presence of wavellite was noted in the pattern of Blichton No. 26 having 8.55% P_2O_5. Wavellite, usually given the formula $2AlPO_4Al(F,OH)_3 \cdot 4\text{-}5H_20$, has been found by Gould[2] to have a characteristic double diffraction peak at 10.38° 2θ because isomorphous substitution of iron was present. This double peak was present in samples that were indicated as having wavellite present. However, if wavellite is the chief phosphatic form, it was not easily detectable by the air drying and glycol-solvation technique employed for these samples. Considerable amorphous material was present in the clays as shown by the diffuse patterns and high backgrounds. The water-dispersed clays were usually high in kaolinite or amohphous material. In the samples where the whole clay was dispersed, vermiculite, kaolinite and quartz were the general patterns present; the Zuber, No. 42, was highest in montmorillonite.

Clay mineralogy data of the soil series sampled in Citrus County are shown in Table 3 and those for Sumter County in Table 4. Note the wavellite identified for Kanapaha, No. 65. Otherwise the mineralogy patterns are like those for the above counties.

The weathering of these soils has proceeded such that the end products of the phosphatic material are not highly crystalline and the other minerals are quite similar from one soil series or one county to another. This might be expected since the weathering sequence of these soils probably was quite similar. Certain of the poorly drained clays might have been protected for a longer time than in the better drained areas. The presence of porous geological formations such as the Ocala Limestone underlying these soils would allow freer leaching and weathering than would occur if impervious geological substance had been present.

ACIDITY AND THE CATION EXCHANGE COMPLEX

The presence of residual geological pebbles of cherty material resembling limestone has led many workers to assume that the soils in these areas are likely to be high in calcium and not to require liming. However, Rowland and Fiskell (6) reported that both exchangeable and total Ca were low in these soils. Since the native vegetation on phosphatic soils is usually dense, plant residues have enriched the first few inches of soil with calcium and other elements. Data reported by Gammon and co-workers (3) showed that calcium usually decreased below the first horizon and Ca, K and Mg together usually accounted for less than 25% of the exchange capacity in these horizons.

In Table No. 5, a detailed study of acidity and exchange factors is reported for several subsoils. All the soils are acid or moderately acid measured in 1:2 suspension of soil and water. When a neutral salt such as KCl is added, a drop in pH occurs. This acidity is titratable and can be partitioned into the Al-hydrolysis component and actual H-ion component by the method of Yuan (8). In Table 5, under titratable acidity, it is seen that most of the released acidity is from Al-ion where the pH fell below

[2]Personal Communication: Robert W. Gould, Assistant in Research, Metallurgy Dept. Univ. of Florida, Gainesville, Florida.

TABLE 2.—THE SAND, SILT, CLAY AND P_2O_5 CONTENT, AND MINERALOGY OF SOIL SERIES SAMPLED IN HERNANDO COUNTY

Soil No.	Soil Series	Depth Sampled	Particle Size Distribution			Total P_2O_5	Clay Mineralogy from X-ray-Diffraction Pattern[1]	
			Sand	Silt	Clay			
		inches	%	%	%	%	H_2O-Dispersed	Whole Clay
24	Arredondo	18-20	57.1	4.7	38.4	0.23	$V_1HM_2K_2$	$K_1V_2Q_3$
27	Arredondo	24-30	69.0	1.1	29.6	1.19	K_1V_3	
28	Arredondo	60-66	73.8	4.7	21.3	1.24	K_1	
38	Arredondo	36-42	55.9	1.4	42.0	.28	K_1A	K_1
39	Arredondo	36-42	67.3	2.4	29.6	.92	K_1A	
40	Arredondo	36-38	82.9	1.2	15.7	69	K_2V_2A	
44	Arredondo	12-15	91.5	3.7	4.6	.10	A	$V_1K_1Q_3$
31	Bladen	24-36	58.9	2.5	38.0	.087		V_2K_2A
25	Blichton	20-30	46.1	3.0	50.2	1.71		$A(W_2)$
26	Blichton	18-24	63.6	7.9	27.3	8.55	K_1W_2V[illegible]	
33	Blichton	20-24	56.0	4.9	38.9	.46	A,K_3	
47	Fellowship	6-20	45.6	4.5	49.2	.35	A,HM_1	
41	Ft. Meade	30-36	89.3	3.8	16.7	3.22		
22	Hague	12-18	40.4	3.6	55.0	.29	$K_2V_2A_2$	K_1V_3
49	Hernando		72.9	1.6	26.2	.04	$K_1HM_2V_2$	V_1K_1A
21	Lakeland	24-36	97.1	.2	2.6	.01		$Q_1V_2K_2Gi_3$
43	Lakeland	24-36	81.5	1.3	17.0	.11		K_1
48	Lakeland	24-40	97.0	.8	2.0	.05		$V_2K_2Q_2Gi_3$
42	Zuber	24-48	56.0	4.2	38.5	3.51		$M_1V_2K_3$

[1]See table 1 for Mineralogical code.

TABLE 3.—THE SAND, SILT, CLAY AND P_2O_5 CONTENT, AND MINERALOGY OF SOIL SERIES SAMPLED IN CITRUS COUNTY

Soil No.	Soil Series	Depth Sampled	Particle Size Distribution Sand	Silt	Clay	Total P_2O_5	Clay Mineralogy from X-ray-Diffraction Pattern[1] H₂O-Dispersed	Whole Clay
		inches	%	%	%	%		
52	Arredondo	24-40	68.5	2.7	28.0	.72		K_1
54	Arredondo	24-36	62.8	1.9	35.0	.21		K_1
51	Lakeland	24-36	97.0	.6	2.6	.10		$V_2K_2Q_2$
55	Lakeland	24-36	97.2	.6	2.0	.09		V_1K_1
56	Lakeland	24-40	95.2	.5	4.3	.22		HM_1A
58	Lakeland	26-40	96.7	.4	2.1	.06		$V_2K_2Q_2$
59	Lakeland	24-36	97.9	.8	1.8	.02		V_1/HM_1
50	Leon	20-30	96.9	.8	1.5	.11		$K_1V_2Q_3$
53	Zuber	24-30	56.9	2.2	40.6	1.26	$K_2Q_3HM_3A$	$K_1V_3Q_3$
57	Zuber	18-20	36.3	1.0	52.0	1.72	A	

[1] Mineralogical code given in Table 1.

TABLE 4.—THE SAND, SILT, CLAY AND P_2O_5 CONTENT, AND MINERALOGY OF SOIL SERIES SAMPLED IN SUMTER COUNTY

Soil No.	Soil Series	Depth Sampled	Particle Size Distribution Sand	Silt	Clay	Total P_2O_5	Clay Mineralogy from X-ray-Diffraction Pattern[1] H$_2$O-Dispersed	Whole Clay
		inches	%	%	%	%		
68	Adamsville	36-42	94.3	4.3	1.3	.32		
69	Adamsville	24-36	95.6	2.9	1.4	.02		Q_1V_2
61	Arredondo	20-36	81.0	4.2	14.3	1.03		K_1HM_2
63	Arredondo	20-24	84.9	2.9	12.3	4.80	A,K_3V_3	K_1
64	Arredondo	below 63	43.3	2.5	53.9	.58	$M_1 (W_2)$	
73	Arredondo	28-36	89.8	3.2	6.4	.25	A,V_3K_3	$K_1V_2Q_3$
77	Arredondo	30-42	77.6	3.7	18.8	1.33	V_1K_2A	
78	Arredondo	30-42	86.0	4.7	8.9	.51	A,V_3K_3	
60	Blanton	20-36	95.7	2.1	2.0	.03		K_1V_2
62	Blanton	24-40	94.1	1.7	4.0	.07		$V_2K_2Q_3A$
70	Blichton	20-30	58.7	4.6	35.7	.92	A,K_3	
71	Blichton	20-30	37.7	1.6	59.4	1.31	A	
72	Blichton	near above	58.9	1.9	36.5	5.38	$M_1V_2K_3$	
76	Bushnell	16-20	48.0	2.0	48.1	.21		K_1
65	Kanapaha	30-36	65.0	1.2	33.0	.84	W_1K_2	
75	Lakeland	24-36	97.1	.5	2.2	.09		$V_2K_2Q_2G_{12}$
67	Panasoffkee	20-30	66.2	1.9	31.1	.16	$K_1V_2HM_2$	K_1V_3
74	Rains	24-28	72.9	3.1	23.4	.18	$V_1HM_2K_2$	

[1]Mineralogical code given in table 1.

4.70. By examination of the exchange capacity and the exchangeable cations calculated as milliequivalents per 100 g. of soil, the Ca, Mg, K and Na occupy a minor part of this exchange. The remaining exchange sites must be either hydrogen or aluminum. The acidity released by the 0.1 N KCl usually is termed the permanent charge. The pH-dependent acidity accounts for the difference between "unaccounted for part" of the exchange capacity listed here as "other" and the titratable acidity figure. The Adamsville, Arredondo, Bladen, Blanton, Blichton, Hague, Lakeland No. 21 and 75, Leon and Zuber have, apparently, a much higher pH-dependent charge or acidity than the Bushnell, Gilead, Kanapaha, Lakeland No. 58 or the Lynchburg soil. These latter soils and Zuber No. 42 have much more actual (non-hydrolysed) H-ion than the other soils in the salt extract. The phosphate content does not appear to be a major factor affecting the acidity properties of these soil samples. Under native conditions the release of Al-ion is likely quite low. However, leaching of fertilizer salts into these subsoils would release high amounts of this element unless the pH could be kept above 5.0.

Several soil samples shown in Table 5 have higher exchangeable magnesium than calcium. Rich and Thomas (5) concluded from their studies that the predominance of Al and Mg in subsurface horizons of acid soils probably is due to the breakdown of clay and then absorption on the remaining clay. In the cases of Arredondo No. 61, Bladen No. 31, Blichton No. 25, Bushnell No. 76, Gilead No. 38, Hague No. 7, Kanapaha from Hardee County, and Zuber No. 42, the level of total P_2O_5 is not involved apparently in the Mg-reaction. A property of these acid clays is to retain Mg preferentially more than Ca on the exchange complex even though the weathering process included either calcareous limestone or apatite breakdown, and possibly both, and released chiefly calcium ions into the soil.

Other soil samples taken during this study were also analyzed for acidity, Table 6. These soils from Pasco County were quite acid except for the Bradenton sample No. 1 which was on limestone. The drop in pH when KCl was added is a ten-fold increase in H-ion present. However, from the titratable acidity very little H-ion was present other than that produced by Al-hydrolysis, the exception being Rex No. 4. Total Ca in these soils is very low compared to Al or Fe. Also $CaCO_3$ was absent in any sample except the above Bradenton soil. The total Ca is likely to be a silicate-form and data to follow indicate Ca-phosphate as improbable unless it is occluded.

Samples from Citrus County are acidic with Arredondo having the highest titratable acidity. Only Zuber No. 57 has appreciable calcium, 0.217%. From Table 2 of the paper by Rowland and Fiskell (6), which lists the exchangeable calcium values on all the samples, in this soil sample 1360 ppm of exchangeable Ca was present.

Samples of the same soil series from Hernando and Sumter County, Table 6, have much the same acidity properties as in Pasco and Citrus Counties. Note however the variability in titratable acidity of the Arredondo and Blichton from several sites. This is caused to some extent by the wide range in clay content which is shown in Table 2 and 4. Clay within 6 inches of limestone may be acidic as shown in Arredondo No. 23 and Blichton No. 29, whereas it is a alkaline in the case of Hernando No. 49. This may be explained by the relationship of the fluctuating water table to the porosity of the limestone although these measurements were

TABLE 5.—EXCHANGE REACTION, CATIONS AND CAPACITY PRESENT IN SUBSOILS OF SEVERAL SOIL SERIES

(expressed on basis of 100 grams of soil)

Soil Number[1]	Soil Series	Depth Sampled	Reaction		Titratable Acidity			Exchange Capacity	Exchangeable Cations				
			H_2O	0.1N KCl	Total	Al+++	H+		Ca	Mg	K	Na	Other[2]
		inches	pH	pH	me	me	me	me	me	me	me	me	me
69S	Adamsville	24-36	5.90	7.12	.18	0.05	0.13	0.90	0.30	0.04	0.00	0.00	0.56
6P	Arredondo	24-36	5.90	4.70	.20	.16	.04	1.63	.03	.05	.02	.00	1.53
61S	Arredondo	20-36	5.75	4.65	.10	.03	.07	10.35	.90	4.00	.03	.03	5.39
31H	Bladen	24-36	4.80	3.70	4.90	4.80	0.10	18.45	.06	1.95	.10	.03	16.31
8P	Blanton	20-30	6.10	4.70	.12	.06	.06	1.75	.03	.02	.01	.00	1.69
62S	Blanton	24-40	5.90	5.10	.55	.05	.50	1.58	.25	.13	.01	.01	1.18
25H	Blichton	20-30	5.20	4.05	2.65	2.50	.15	19.00	5.50	4.60	.07	.02	8.81
26H	Blichton	18-24	5.63	4.27	.19	.02	.17	15.50	1.40				
76S	Bushnell	16-20	5.15	3.80	6.70	4.55	2.15	13.30	3.05	2.20	.01	.03	8.01
9P	Gilead	20-30	4.85	4.05	7.85	5.45	2.30	9.45	.06	1.38	.01	.00	8.00
7P	Hague	20-30	5.52	4.70	.18	.03	.15	8.25	.55	2.87	.01	.05	4.77
HA	Kanapaha	30-48	4.75	3.85	5.20	3.96	1.24	8.35	.05	1.28	.01	.03	6.96
58C	Lakeland	26-40	5.95	4.70	.45	.30	.15	.92	.26	.05	.01	.01	.59
21H	Lakeland	24-36	6.55	5.55	.07	.02	.05	.85	.09	.04	.00	.01	.71
75S	Lakeland	24-36	5.85	4.80	.28	.25	.03	1.82	.20	.59	.04	.00	.99
14P	Leon	24-36	5.93	4.30	.38	.30	.08	1.80	.05	.10	.01	.00	1.64
18P	Leon	24-30	5.15	3.75	1.55	.60	.75	3.45	.05	.18	.01	.00	3.21
50C	Leon	20-30	6.15	5.55	.05	.03	.02	3.38	.35	.38	.00	.10	2.55
3P	Lynchburg	24-36	6.30	5.00	.65	.20	.45	1.08	.25	.05	.00	.00	.78
42H	Zuber	24-48	5.15	3.80	7.45	5.28	2.17	17.10	.90	4.78	.09	.05	11.28
PO	Zuber	24-30	4.85	4.35	.80	.75	.05	5.10	1.25	1.00	.11	.01	2.74

[1]Capital letter after the soil sample number gives the county: C—Citrus, HA—Hardee, H—Hernando, P—Pasco and S—Sumter.

[2]"Other" indicates exchange sites of the exchange capacity not occupied by Ca., Mg, K or Na.

TABLE 6.—ACIDITY FACTORS AND TOTAL ANALYSIS OF SEVERAL SAMPLES OF SOIL SERIES FROM WEST CENTRAL FLORIDA

Soil Number	Soil Series	Depth Sampled	Soil Reaction: H_2O Suspension	Soil Reaction: 0.1N KCl Suspension	Titratable Acidity per 100 gm. soil: Total	Titratable Acidity per 100 gm. soil: Al^{+++}	Titratable Acidity per 100 gm. soil: H^+	P_2O_5	Total Analysis: Ca	Total Analysis: Al	Total Analysis: Fe
		Inches	pH	pH	me	me	me	%	%	%	%
					Pasco County						
10	Arredondo	24-36	5.10	4.32	0.11	.10	.01	0.85	.030	6.30	2.40
11	Arredondo	24-30	4.98	4.18	.22	.11	.11	.30	.000	4.00	.74
12	Arredondo	20-30	4.35	3.88	.62	.44	.18	.89	.000	2.60	.73
2	Blanton	24-36	4.80	4.35	.50	.45	.05	.06	.14*	.17	.03
1	Bradenton	3-6 disturbed	7.95	7.00	.00	.00	.00	.07	free	4.80	1.70
17	Bushnell	20-24	5.08	3.88	6.81	6.80	.01	.08	.079	3.12	1.82
15	Gainesville	60-66	5.30	3.73	5.06	1.23	.83	1.13	.088	2.10	.56
16	Hague	36-48	5.32	4.06	.91	.84	.07	3.20	.105	3.12	1.68
5	Fellowship	18-24	5.14	4.12	1.42	1.32	.10	8.00	.049	7.00	2.00
19	Leon	24-36	5.20	4.48	.09	.08	.01	.03	.000	2.40	.21
4	Rex	6-12	5.38	3.93	5.50	4.30	1.20	.14	.033	2.00	1.10
13	Rex	24-36	5.00	3.92	1.60	1.48	.12	.14	.000	3.80	1.00
					Citrus County						
52	Arredondo	24-40	5.05	4.00	4.35	4.30	.05	.72	.15*	5.92	.44
54	Arredondo	24-36	5.12	4.15	3.35	2.65	.70	.21	.14*	2.96	1.26
51	Lakeland	24-36	5.95	4.70	.35	.30	.05	.10	.15*	.37	.14
55	Lakeland	24-36	5.60	4.55	.20	.14	.06	.09	.19*	.40	.14
56	Lakeland		5.85	5.32	.12	.01	.11	.22	.12*	.78	.26
59	Lakeland	24-36	5.90	5.50	.25	.05	.20	.02	.05*	.14	.03
53	Zuber	24-30	5.32	4.04	.90	.88	.02	1.26	.097	3.00	1.08
57	Zuber	18-20	5.75	4.41	.36	.26	.10	1.72	.217	2.98	1.52
					Hernando County						
23	Arredondo	6″ over lime	6.65	5.38	.02	.00	.02	.53	.050	9.60	3.70
24	Arredondo	18-20	5.01	3.96	1.09	1.05	.04	.23	.113	2.03	1.63
27	Arredondo	24-30	4.88	3.95	1.60	1.53	.07	1.19	.077	1.55	.44
28	Arredondo	60-66	4.89	4.02	1.07	.69	.38	1.24	.044	.50	.05

TABLE 6.— (Concluded)

Soil Number	Soil Series	Depth Sampled	Soil Reaction H_2O Suspension	Soil Reaction 0.1N KCl Suspension	Titratable Acidity per 100 gm. soil Total	Titratable Acidity per 100 gm. soil Al^{+++}	Titratable Acidity per 100 gm. soil H^+	P_2O_5	Total Analysis Ca	Total Analysis Al	Total Analysis Fe
		Inches	pH	pH	me	me	me	%	%	%	%
38	Arredondo	36-42	4.87	4.03	.88	.85	.03	.28	.000	8.78	.94
39	Arredondo	36-42	4.83	3.91	1.06	1.00	.06	.92	.000	4.80	.47
40	Arredondo	36-48	5.31	4.00	.48	.37	.11	.69	.000	2.70	.43
44	Arredondo	12-15	5.49	4.35	.11	.09	.02	.10	.030	2.45	.21
25	Blichton	20-30	5.20	4.05	2.50	2.40	.10	1.71	.20*	6.80	2.45
26	Blichton	18-24	5.63	4.27	2.19	2.09	.10	8.55	.03	7.70	1.83
29	Blichton	6" above to lime	4.98	3.77	1.15	1.00	.15	.92	.000	6.40	3.50
30	Blichton	12-36	4.50	3.90	.77	.61	.16	1.01	.000	2.20	.74
32	Blichton	48-54	5.36	3.64	.52	.35	.17	1.19	.000	6.40	1.90
33	Blichton	20-24	5.05	3.95	.91	.85	.06	.46	.040	3.70	.81
37	Blichton	22-24	4.91	3.65	2.55	2.20	.35	3.02	.040	8.20	3.10
35	Blanton	24-36	5.13	4.33	.17	.10	.07	.09	.000	.70	.56
36	Blanton	24-30	5.12	4.65	.06	.01	.05	.11	.000	.80	.25
47	Blanton	6-20	5.40	3.98	.28	.26	.02	.35	.140	15.20	.30
41	Ft. Meade	30-36	5.69	4.78	.03	.02	.01	3.22	.000	4.85	.82
22	Hague	12-18	6.01	5.80	.91	.30	.61	.29	.130	1.98	1.69
49	Hernando	over lime	8.11	7.43	.00	.00	.00	.04	7.50	5.10	.48
20	Lakeland	36-45	6.49	5.83	.03	.01	.02	.03	.000	.10	.07
43	Lakeland	24-36	5.10	4.20	.50	.35	.15	.11	.10*	4.01	1.50
48	Lakeland	24-40	5.93	4.65	.15	.05	.10	.05	.14*	.44	.06
					Sumter County						
68	Adamsville	36-42	5.73	4.86	.35	.13	.23	.32	.000	.26	.04
63	Arredondo	20-24	5.88	5.03	.02	.01	.01	4.80	.350	7.65	1.12
64	Arredondo	clay deposit	5.92	4.32	.08	.06	.02	.58	.220	16.55	1.30
73	Arredondo	28-36	5.55	4.55	.05	.03	.02	.25	.04	5.10	.37
77	Arredondo	30-42	6.92	6.15	.012	.010	.002	1.33	.060	3.20	.88
78	Arredondo	30-42	5.91	4.81	.020	.010	.010	.51	.000	2.70	.43
60	Blanton	20-36	5.55	4.50	.40	.18	.22	.03	.15*	.21	.02
62	Blanton	24-40	5.90	5.10	.05	.00	.05	.07	.09*	.14	.04
70	Blichton	20-30	5.54	4.56	.02	.02	.00	.92	.030	7.35	1.07
71	Blichton	20-30	5.01	3.80	.80	.41	.39	1.31	.610	11.00	.82
72	Blichton	24-36	5.88	4.49	.06	.05	.01	5.38	.700	16.40	2.64
65	Kanapaha	30-36	6.55	5.76	.01	.00	.01	.81	.070	5.60	.23
67	Panasoffkee	20-30	4.85	3.71	2.40	1.10	1.30	.16	.030	7.10	.55

not taken. These numerous samples indicate that at pH 4.8 or above in salt solution very little titratable acidity is present. The observation made above, that total P_2O_5 is not directly involved in the degree of titratable acidity, is substantiated throughout these samples. Obviously this phosphate does not regulate the aluminum activity possibly because the phosphate has reacted completely, forming quite inert Al and/or Fe phosphates in the presence of other amorphous compounds which would assume their normal properties with time.

NATURE OF THE SOIL PHOSPHATE

Since apatite is the mineral form of the phosphate in the hard rock phosphate and pebble phosphate deposits in Florida, it has been assumed that the phosphatic soils were also high in this mineral. From total analysis of the soil only a small part of the P_2O_5 could be accounted for by the total Ca present. In Table 6, in every case where the total P_2O_5 is above 1%, Ca is less than 0.20%. The ratio of total P_2O_5 to Ca in apatite is 1.1:1.2 or nearly unity. Therefore, apatite and calcium phosphates are not likely present in large amounts. However, Al in all these soils is present in sufficient amounts to account for the presence of all the phosphate in this form although the iron content is also high enough so that isomorphous iron phosphates could also be present. As noted above, a pattern for wavellite was observed in a few cases.

Chang and Jackson (1) have defined the separation of phosphate forms on the basis of their solubility in various reagents used in sequence. This method with slight modifications was used on a number of soils in this study. In Table 7, the total analysis and fractionation of soil phosphate are shown. Each soil series bears discussion. Adamsville with 0.02% phosphorus or 200 ppm expressed as P, contains 4 ppm. of P extracted by neutral normal ammonium acetate at pH 4.8. Using 0.5 N NH_4F, which extracts aluminum phosphate, 26 ppm of P are made soluble. When dilute sodium hydroxide is the extractant, 7 ppm of P classified as iron phasphate, is solubilized. Since only 1ppm of P is found from extraction with 0.5 N sulfuric acid, this indicates that apatite is not more than this amount. Removal of the free iron oxides by reduction with $Na_2S_2O_4$ in 0.4M sodium citrate released 40 ppm of P and is termed the reductant soluble iron phosphate. This means iron layers on the phosphate protected it from extraction along with the previous iron phosphate soluble in dilute NaOH. When the soil was subjected to dilute NaOH treatment a second time, 12 ppm of P was found; probably freed from occlusion in hydrated iron or aluminum oxide. In the case of Arredondo No. 61, total analysis by acid extraction indicates aluminum phosphate is present and solubility sequence shows that phosphate including the occluded form is 2,440 ppm in the aluminum form compared to 450 in the iron form and 8 as apatite-like. Bladen, No. 31, appears to have more phosphorus in the iron form, although the amounts are low. Blanton has both iron and aluminum phosphates present. The samples of Gilead, Lakeland, Leon and Lynchburg show that the most of the phosphate is in Al or Fe forms from solubility data, and is principally in the occluded state.

There is a strong indication that apatite-like phosphate may be present in the Blichton, Hague, Kanapaha and Zuber soil series. However, as shown in Table 7, here again aluminum phosphate is much more abundant

TABLE 7.—NATURE OF THE PHOSPHATE IN THE SUBSOIL OF SEVERAL SOIL SERIES FROM COUNTIES IN WEST CENTRAL FLORIDA AS SHOWN FROM TOTAL ANALYSIS AND SOLUBILITY IN SEVERAL REAGENTS USED IN SEQUENCE

Soil Number[1]	Soil Series	Depth Sampled	Total Analysis P	Total Analysis Al	Total Analysis Fe	Ca[2]	Phosphate Solubilized in Sequence: NH_4Ac N, pH 4.8	NH_4F 0.5N	NaOH 0.1N	H_2SO_4 0.5N	Sulfite-Citrate	NaOH 0.1N	Free[3] Iron
		Inches	%	%	%	%	ppm P	ppm P	ppm P	ppm P	ppm P	ppm P	mgm Fe
69S	Adamsville	24-36	0.02	0.12	0.03	0.13	4	26	7	1	40	12	0.28
6P	Arredondo	24-36	.33	.30	.07	.15	8	20	122	----	----	----	----
61S	Arredondo	20-36	.44	.81	.11	.09	1	240	250	8	200	2,200	13.80
31H	Bladen	24-36	.04	7.39	.24	.16	2	15	20	4	116	44	12.80
8P	Blanton	20-30	.06	.39	.03		4	82	27	1	4	37	.13
62S	Blanton	24-40	.05	.44	.04	.09	4	22	110	3	220	220	1.32
25H	Blichton	20-30	.76	6.82	2.45	.20	36	1,160	2,050	660	1,380	3,160	41.50
76S	Bushnell	16-20	.21	3.10	.93	.13	6	25	244	7	500	880	22.10
9P	Gilead	20-30	.03	2.72	.74	.62	6	36	32	8	48	166	.56
7P	Hague	20-30	.19	2.32	.73	.11	36	370	240	60	380	1,200	6.00
HA	Kanapaha	30-48	.58	6.26	.32	.01	46	1,320	500	120	1,110	1,720	3.20
58C	Lakeland	26-40	.02	.44	.20	.19	6	38	34	2	12	63	1.07
21H	Lakeland	24-36	.01	.17	.04	.25	6	14	9	N.D.	8	...	.11
75S	Lakeland	24-36	.03	.22	.17	.13	4	21	24	2	28	23	.40
14P	Leon	20-30	.02	.25	.02	.12	2	4	10	N.D.	50	22	.02
18P	Leon	24-30	.01	.12	.00	.05	2	12	1	6	44	18	.04
3P	Lynchburg	14-36	.01	.31	.08		6	10	10	2	42	10	.14
42H	Zuber	24-48	1.54	6.00	4.27	.15	48	3,480	480	80	1,150	9,640	13.10
PO	Zuber	24-30	.42	8.14	3.80	.13	10	620	44	7	1,000	2,400	14.30

[1]Capital letter after the soil sample number gives the county: C—Citrus, PO—Polk, HA—Hardee, H—Hernando, P—Pasco and S—Sumter.

[2]Free iron determined in filtrate after the hydrosulfite citrate extraction.

[3]Calcium determined in clay fraction only.

and iron phosphate more abundant than the calcium phosphate. This is borne out by the values found from acid digestion of these soils. In the case of Blichton No. 25, the amount of phosphorus recovered by the solubility hequence is 0.84% of the soil compared to 0.76% from the acid digestion. The clay fraction contained 1.74% of P which is 0.87% on the basis of the whole soil. This indicates the phosphate in this sample is in the clay fraction and is free of coarser phosphate material. In the above Blichton and in Bushnell, No. 76, iron phosphate is more abundant than aluminum phosphate and these soils have the highest free iron content. The Hague, Kanapaha and Zuber soil samples appear to be higher in aluminum phosphate than iron phosphate according to their solubility. Considering all the operations involved in the solubility sequence, the recoveries are in good agreement with the total phosphorus value found by acid digestion.

From the total potassium-analysis of phosphatic soils, the possible amount of K-bearing phosphates such as tarankite or minyulite is very low. Most of these clays contained from 0.10 to 0.20% of K; the highest was 0.36% in Blichton No. 25, which has 3.5% P_2O_5 in the clay fraction. Nonphosphatic soils with similar texture also contained about the same amount of total K in the clay as did the phosphatic soils. The total K more likely is present as illite and possibly as feldspars; these minerals were below the detection limits of the X-ray diffraction method.

CONCLUSIONS

From the foregoing data and the geological correlation with soil series certain conclusions can be drawn. These are as follows:

1. Assuming that major amounts of phosphate did not leach from finer textured soils, phosphatic soils such as Blichton, Fellowship and Arredondo must have developed from phosphatic deposits. In the same county, however, such soils as Rex, Bushnell, Gilead and Lakeland must have developed from non-phosphatic materials. The latter soils probably were formed first before the arrival of the phosphatic deposits, or are derived from erosional exposure and weathering of the earlier geological formations.
2. Certain soils classified as non-phosphatic because the total P_2O_5 is less than 0.23% were likely derived partially from the phosphatic formation because the clay fraction is phosphatic. Certain Blanton, Leon, and Lakeland sites indicated this was the case.
3. The weathering of the phosphate, assumed to be apatite as is found in the geological formation, was found to progress to aluminum phosphate primarily. Isomorphous substitution with iron occurred where the clays were comparatively high in iron content as shown by present total iron and free iron analysis. It can be assumed that a small part of the phosphate is residual apatite if the solubility method is valid for these soils. Total calcium also was sufficient to account for some apatite being present. This phosphate might have not reacted completely with the soil because layers of quite insoluble Al and Fe hydroxides and phosphates protected it from attack by the acid soil.
4. Calcareous residues of the geological material were not found in the subsoils. Furthermore the total calcium indicated that the

calcium had leached from the clay. Exchangeable calcium was low in practically all the soil series that were sampled. Weathering of these soils produced acidity. The present titratable acidity was found to be chiefly aluminum hydrolysis in the presence of a neutral salt. Salt water intrusions might have started some of this calcium removal and the aluminum replacement during the several ages that the land has been under the sea. The rapid interior drainage of most of these soils assisted the weathering process.

5. Mineralogical data support the evidence that these soils are highly weathered. Much of the clay is not crystalline which showed that the layer lattice structure had been broken down. Crystalline minerals present in the samples of most soil series are kaolinite, vermiculite, quartz, and in some samples hydrous micas, montmorillonite, gibbsite, and wavellite. These clays are not high in exchange capacity, about 20-30 me per 100 grams. The phosphatic soils possessed a swelling property not attributable to expanding 2:1 lattice minerals. The clays condensed in salt solution to fluffy, irregular shapes and were not collapsed to near the degree found for similar amounts of non-phosphatic clays from the same general area. The existence of highly hydrated, poorly oriented and amorphous-like materials was indicated.

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LITERATURE CITED

1. Chang, S. C. and M. L. Jackson. Fractionation of soil phosphorus. Soil Sci. 84:133-144. 1957.
2. Fiskell, J.G.A., N. Gammon Jr., T. L. Yuan, and O. Zmeskal. Colloidal properties of some Florida soils. Soil Sci. Soc. Amer. Proc. 22:339-343. 1958.
3. Gammon, N. Jr. et al. Physical, spectographic and chemical analysis of some virgin Florida soils. Fla. Agr. Expt. Sta. Tech. Bul. 524. 1953.
4. Mehlich, A. Improvements in the colorimetric magnesium and ammonium methods with polyacrylate. J. Assoc. Official Agr. Chem. 39:518-523. 1956.
5. Rich, C. I. and G. W. Thomas. The clay fraction of soils. Advances in Agronomy 12:1-39. 1960.
6. Rowland, L. O. and J.G.A. Fiskell. Correlation studies of geology with soils of West Central Florida. Soil and Crop Soc. Fla. Proc. 20: p. 110. 1960.
7. Sandell, E. B. Colorimetric Determination of Traces of Metals. Interscience Publishers Inc., New York (1950) pp. 376-378.
8. Yuan, T. L. Determination of exchangeable hydrogen in soils by a titration method. Soil Sci. 88:164-167. 1959.
9. Yuan, T. L. and J.G.A. Fiskell. Aluminum studies: 1. Soil and plant analysis of aluminum by a modification of the aluminon method. J. Agr. and Food Chem. 7:115-117. 1959.

Certain Factors Affecting the Leaching of Potassium From Sandy Soils[1]

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INTRODUCTION

The mineral soils of Florida are generally coarse textured and classified as sands, loamy sands, or sandy loams. These soils are inherently low in potassium bearing minerals; therefore, potassium fertilizers are used extensively in the production of all the principal crops. Annual applications range from 50 to 100 pounds of K_2O per acre for most pasture and field crops and as much as 200 to 400 pounds per acre for many vegetable and fruit crops.

Although potassium fertilizers are generally applied to Florida soils in greater quantities than actually removed in the harvested crop, accumulation of potassium in cultivated soils is rarely reported. Blue *et al.* (2) reported no appreciable accumulation of potassium in the top 30 inches of Leon sand that had been heavily fertilized over a period of 40 years in the growing of celery. A number of factors, such as rates and placement of fertilizers, ion balance in the fertilizer zone, soil cover, and amounts and intensity of rainfall, have been reported to influence leaching of potassium in sandy soils. The purpose of this investigation was to more closely relate the above factors to potassium movement in mineral soils.

LITERATURE REVIEW

Peech (11) noted direct relationships between organic matter content and base exchange capacity with the retention of potassium in soils in Florida. Collison (3) also found that the organic matter content was a significant factor in the retention of potassium in virgin sandy soils of Florida. A number of workers (9, 10, 15) have demonstrated that liming acid soils improves the retention of added potassium. Thomas and Coleman (13) attributed the greater potassium retention from calcium saturated soils over aluminum saturated soils to the increase in exchange capacity after liming an acid soil, as well as the replacement of aluminum by calcium on the exchange complex. Peech (11) and other investigators (1, 6, 12), however, concluded that potassium applied in the form of neutral salts was subject to rapid leaching in light sandy soil regardless of soil reaction.

Volk and Bell (16) showed that the nature of the cation-anion balance is of major importance in the kinds and amounts of salts appearing in the leachates. (Unused nitrogen of fertilizers tends to increase the leaching of potassium and other cations.) McIntire *et al.* (7) reported that the larger the addition of potassium at one application, the greater was the total loss of potassium. Volk and Bell (16) found that the leaching losses of calcium and potassium from cropped lysimeters were higher from broad-

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cast than from band applications. However, from fallow lysimeters, leaching losses were greater from band applications.

The intensity of rainfall has been demonstrated to affect the leaching losses of potassium. Allison *et al.* (1) reported that 23% of the potassium leached from lysimeters during a seven-year study was collected during a six-month period of especially heavy rainfall. Truog and Jones (14) reported that plants growing on the soil are an important means of retaining potassium in sandy soils. Other workers (1, 5, 16) have shown the beneficial effect of crops in preventing potassium from leaching from sandy soils.

EXPERIMENTAL METHODS

A number of factors affecting the movement of potassium were studied in outside lysimeters, in greenhouse lysimeters and in the laboratory. Lysimeter experiments were conducted with both summer and winter crops. The treatments in the large outside lysimeters are given in Table 1. These lysimeters were saturated with tap water and allowed to drain free of gravitational water just prior to the first treatments. Phosphorus from concentrated superphosphate and nitrogen from NH_4NO_3 were

TABLE 1.—THE EFFECT OF BROADCAST AND BAND PLACEMENT OF THREE RATES OF KCl ON THE LEACHING OF POTASSIUM FROM ARREDONDO FINE SAND IN OUTSIDE LYSIMETERS.

Treatment Number	Treatment K_2O	Placement	Crops	Rainfall passing through soil		Potassium in leachate
	Lbs/A			Inches	%	me
			Winter crops			
1	60	Band	Cabbage	19.13	65.5	11.44
7	60	Broadcast	Cabbage	18.76	64.3	10.94
8	60	Broadcast	Oats	11.54	39.5	7.02
9	60	Broadcast	Fallow	22.67	77.6	14.88
3	120	Band	Cabbage	19.89	68.1	10.43
11	120	Broadcast	Cabbage	19.04	65.2	11.86
10	120	Broadcast	Oats	10.07	36.7	9.41
5	120	Broadcast	Fallow	23.05	79.0	15.10
2	240	Band	Cabbage	19.35	66.3	13.69
12	240	Broadcast	Cabbage	18.36	62.9	13.54
6	240	Broadcast	Oats	10.50	36.0	8.63
4	240	Broadcast	Fallow	23.37	80.0	33.31
			Summer crops			
1	60	Band	Sweet potato	14.01	42.3	14.95
7	60	Broadcast	Sweet potato	16.64	50.7	16.71
8	60	Broadcast	Millet	12.32	37.2	10.62
9	60	Broadcast	Fallow	20.89	62.7	145.24
3	120	Band	Sweet potato	13.91	42.0	44.85
11	120	Broadcast	Sweet potato	13.66	41.2	24.97
10	120	Broadcast	Millet	11.14	33.6	16.94
5	120	Broadcast	Fallow	20.56	62.0	267.97
2	240	Band	Sweet potato	12.89	38.9	201.33
12	240	Broadcast	Sweet potato	12.48	37.7	89.91
6	240	Broadcast	Millet	11.12	33.5	47.49
4	240	Broadcast	Fallow	20.78	62.7	894.98

applied along with KCl, chloride as a mixed fertilizer, at planting. Leachings were collected continuously during the period of the experiments. The quantities of leachings were measured and aliquots taken and analyzed for nitrogen, calcium, magnesium, potassium and chloride content. Soil samples from each lysimeter were taken at depths of 0 to 12 and 12 to 24 inches before the initial treatments were applied, at the end of the winter crops and after the last crops were harvested. Cation exchange capacity, exchangeable calcium, magnesium and potassium were determined for each sample.

A greenhouse experiment was conducted to study the effect of cropping systems and leaching rates on the leaching of potassium from Lakeland fine sand. The soil was air-dried, screened and weighed into three-gallon leaching pots. Variations were made in cropping practices and leaching variables. The crop variables included millet, radish and fallow, while leachings variables included 3½ and 7 inches of leachate collected per pot. The crops were grown for a period of three weeks, and then 3½ inches of deionized water was leached through each pot to remove any excessive potassium from the soil. After a one-week period, 100 pounds of K_2O per acre from KCl were applied in solution to the soil surface. Leaching was begun 24 hours later by the addition of deionized water at a rate that delivered a total of 3½ or 7 inches of leachate in 48 hours. The leachate was analyzed for potassium content.

The effect of soil reaction on the retention of potassium in sandy soils was studied in a laboratory experiment. Bulk samples of Lakeland and Red Bay soils were placed in separate containers and the pH adjusted to varying levels by the addition of sulfur or calcium hydroxide. The pH values of the two soils were adjusted as follows: Lakeland 4.2, 5.3, 6.3 and 8.3; and Red Bay 4.6, 5.3, 6.7 and 8.1. Soils from each adjusted sample were placed in six-inch leaching tubes, and KCl was added in solution at the rate of 100 ppm of K_2O. Two days were allowed for reaction with the soil after which the tubes were leached with deionized water. Ten inches of leachate, in increments of 2 inches, were collected from each tube and each increment analyzed for potassium content. The cation exchange capacity of the adjusted soils was determined with neutral normal ammonium acetate.

RESULTS AND DISCUSSION

Lysimeter experiment

The amounts of rainfall that percolated through the soil and the potassium content of the leachates are presented in Table 1. There were 62.4 inches of precipitation during the 11 months of the study, with 29.2 inches falling during the winter and 33.2 inches falling during the summer. The leaching losses of potassium were quite small from all treatments during the winter months (Table 1). The loss of potassium from the highest rate of KCl on the oat plots was less than 1% of the amount applied in the fertilizer. Potassium leached from the fallow soil receiving 240 pounds of K_2O per acre was 33.31 me or 2.8% of the amount added.

These soils contained a relatively small amount of exchangeable potassium before treatments were applied as shown by data from the first sampling period (Figure 1). Therefore, when added potassium was not removed by the plant, it was retained on the exchange complex of the

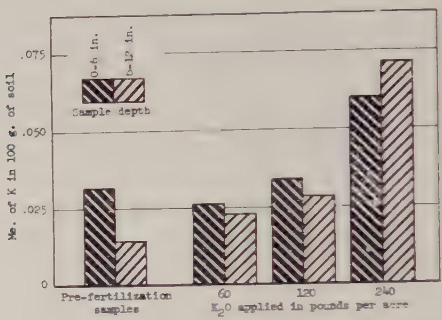

Fig. 1.—The average content of exchangeable K (me. per 100 g. of soil) in surface (0-12 in.) and subsurface (12-24 in.) samples taken before fertilization and after harvest of winter crops receiving varying ratios of K_2O per acre.

soil. It is evident from the results of the second sampling period that exchangeable potassium was greater in the soil samples taken after the winter crops were harvested than in the original samples.

Much greater amounts of potassium were leached from the soil during the summer than during the winter period (Table 1). However, the losses of potassium from the millet and potato crops were small; less than 18% of the 240-pound application leached from the soil. The greatest loss of potassium (183 pounds per acre) during the summer was from the fallow soil which received 240 pounds of K_2O per acre. This represents a total loss equivalent to 76.2% of the potassium added for the summer crops. This indicates that the capacity of the soil to retain added potassium was about saturated after the first addition of 240 pounds of K_2O, which resulted in nearly all of the second increment of potassium leaching from the soil.

Potassium lost from the 240-pound-per-acre rate on sweet potatoes was 41 pounds from band as compared with 18 pounds of K_2O from broadcast applications. Since the cation exchange capacity was very low (around 2.5 me per 100 g. of soil), the increased contact between the applied potassium and the soil particles from the broadcast placement undoubtedly enhanced the retention of potassium.

All crops were effective in reducing the leaching losses of potassium during both periods of study (Table 1). Undoubtedly, crops reduce the leaching losses of potassium through assimilation of this nutrient into their tissues, as well as through a reduction in water percolation through the soil. The relative importance of these two functions probably varies with crops and soil condition, but the following example may give some idea of their value in the conservation of potassium. The water leached through the fallow lysimeter represented 70.2% of the rainfall, while that leached from the cabbage and potato plots was 52.7% of the rainfall. The crop reduced the loss by 25%. On the other hand, potassium leached from fallow plots was equivalent to 39.1% of the 480 pounds of K_2O added, while that lost from the cabbage-potato plots was only 9.5%, or a reduction of 76%.

Greenhouse experiment

The effect of cropping system on the amounts of residual potassium leached from Lakeland fine sand is presented in Table 2. There were

highly significant differences in the amounts of potassium leached from the soil among the fallow, radish and millet treatments. Since nitrogen was added uniformly to all pots, a high concentration of nitrate ions might account for the large loss of potassium from the fallow soil. The differences in potassium leached from the two crops may be attributed to greater absorption of potassium by the millet.

The amounts of potassium applied as top-dressing that leached from the fallow, radish and millet treatments are shown in Table 2. A total of 88.6 and 164.8% of the added potassium leached from the fallow soil with 3½ and 7 inches of water, respectively. Increasing the intensity of leaching from 3½ to 7 inches also increased the amount of potassium lost from soils growing millet and radish crop. However, the total amounts of potassium lost as a result of either rate of leaching were very small. These results again point out the importance of crops in retention of soluble potassium in sandy soils against the leaching action of heavy rains. Under field conditions, very little potassium would be lost by leaching from normal application of KCl to plants with well-established root systems.

TABLE 2.—THE EFFECT OF TWO LEACHING RATES ON THE AMOUNTS OF POTASSIUM LEACHED FROM LAKELAND FINE SAND WITH FALLOW, RADISH AND MILLET CROPS RECEIVING 100 POUNDS OF K_2O PER ACRE.

Leaching	Potassium leached		
	Fallow	Radish	Millet
inches	mg.	mg.	mg.
3½	425.1	24.3	15.4
7	790.8	30.8	43.1

Laboratory experiment

The effect of soil pH on the amount of potassium leached and the calculated percentage of added potassium leached is presented in Table 4. The amounts of potassium leached from Lakeland soil ranged from 6.0 mg. at pH 6.3, or a total of 41.4% of that added, to 18.0 mg. at pH 8.3, or 124.1% of the amount added. A total of 10.7 mg., or 73.1% of the added potassium, leached from the untreated Lakeland soil with pH of 5.3. In contrast, the original Red Bay soil (pH 5.3) retained 88% of the added potassium against loss by leaching. The amounts of potassium leached from Red Bay soil ranged from 1.1 mg. at pH 6.7 to 5.5 mg. at pH 4.6. These amounts represent 8.3 and 41.3% of the added potassium for the two soil pH levels, respectively.

The cation exchange capacities increased with each rise in pH of Lakeland soil (Table 3). The increase in exchange capacity when the soil pH was raised from 4.2 to 8.3 amounted to 56%. The exchange capacity of the Red Bay soil increased from 7.07 me at pH 4.6 to 10.8 at pH 6.7. However, the exchange capacity declined when the soil reaction was raised from pH 6.7 to 8.1.

The retention of potassium added to these soils was closely related to the exchange capacities at the various pH levels, except at the highest

TABLE 3.—EFFECT OF VARYING SOIL PH ON LEACHING OF POTASSIUM AND CATION EXCHANGE CAPACITY OF LAKELAND AND RED BAY SOILS.

Soil pH	Added* potassium leached		Cation Exchange Capacity
	mg.	%	me/100 g.
	— Lakeland fine sand —		
4.2	16.2	111.7	2.10
5.3	10.7	73.1	2.67
6.3	6.0	41.4	3.03
8.3	18.0	124.1	3.28
	— Red Bay loamy fine sand —		
4.6	5.5	41.3	7.07
5.3	1.6	12.0	8.95
6.7	1.1	8.0	10.76
8.1	1.8	13.5	8.78

*KCl added at the rates of 14.50 and 13.75 mg. of K per tube of Lakeland and Red Bay soil, respectively—equivalent to approximately 200 pounds of K_2O per acre.

pH value in Lakeland sand. The increase in amounts of potassium leached from Lakeland soil when the pH was raised to 8.3 was probably due to the high concentration of calcium ions replacing potassium from the exchange complex of the soil by mass action. There was a small increase in amounts of potassium leached at pH 8.1 from the Red Bay soil; however, it was not significantly higher than at pH 5.3 or 6.7 and is apparently related to a decrease in exchange capacity at this higher pH value.

In Lakeland fine sand a soil pH of about 6.5 appears to be the most favorable pH level for the retention of applied salts. Although the cation exchange capacity increases with increasing pH, the mass action effect of calcium apparently dominates the exchange reaction at the higher pH levels. Therefore, under normal field conditions, liming to maintain the pH of the soil from 6.0 to 6.5 should result in maximum retention of applied potassium salts on Lakeland fine sand. On the Red Bay soil, however, the pH would not affect the retention of applied potassium except at abnormally low or very high pH levels.

SUMMARY AND CONCLUSIONS

A series of experiments was conducted in large lysimeters, in the greenhouse and in the laboratory to study certain factors related to leaching of potassium from mineral soils. The following variables were investigated and their relationship to potassium leaching discussed: soil cover, rates and methods of application of potassium fertilizers, leaching intensity and soil reaction.

Crops growing on the soil reduced the leaching losses of potassium in outdoor and greenhouse experiments. This reduction in leaching losses of potassium by plants was affected through a reduction in the amount of gravitational water passing through the soil and by absorption of fertilizer potassium into the plant tissues.

The type of crop or root systems of crops greatly affected the leaching

of potassium. A combined oat and millet crop reduced the leaching of potassium from an application of 480 pounds of K_2O per acre by 46.3% when compared with potassium leached from the same rate of KCl on cabbage and sweet potato crops.

Potassium losses from Arredondo fine sand increased with each increment of KCl added to cropped and fallow soils. Potassium leaching losses were greater from band placement of KCl than from a broadcast application on sweet potato plots.

Soil reaction significantly influenced the amounts of potassium retained in Lakeland fine sand in a laboratory study. The average leaching losses of potassium at pH 4.2 were 1¾ times greater than at pH 5.3 and 2¾ times greater than at pH 6.3. The amounts of potassium lost from Red Bay loamy fine sand were relatively small, even at low pH levels. However, the influence of pH on potassium losses from this soil was similar to that observed with Lakeland sand. The reduction in potassium losses in soils limed to near neutrality is probably due to (1) an easier substitution of potassium for calcium than for hydrogen or aluminum on the exchange complex and (2) an increase in the effective exchange capacity of the soil.

Data obtained from these experiments indicate that the following practices would be advantageous for the conservation of potassium in Florida soils: 1. A cover crop should be maintained on the soil whenever possible. 2. Relatively small amounts of potassium salts should be applied at each application. 3. Where large amounts of potassium salts are added in single applications, they should be applied broadcast rather than by band placement. 4. The soil pH should be maintained from 6.0 to 6.5 through proper liming practices.

LITERATURE CITED

1. Allison, F. E., E. M. Roller and J. E. Adams. Soil fertility studies in lysimeters containing Lakeland sand. U. S. Dept. Agr. Bul. 1199. 1959.
2. Blue, W. G., C. F. Eno and P. J. Westgate. Influence of soil profile characteristics and nutrient concentrations on fungi and bacteria in Leon fine sand. Soil Sci. 80: 303-308. 1955.
3. Collison, S. E. Citrus fertilizer experiments. Florida Agr. Expt. Sta. Bul. 154. 1919.
4. Gammon, N., Jr. The behavior of potassium and potassium fertilizers in Florida soils. Soil and Crop Sci. Soc. Fla. Proc. 17: 156-160. 1957.
5. Gow, P. S. A lysimeter study of losses of applied potassium by leaching from an acid soil. Hawaiian Plant Rec. 43: 263-276. 1939.
6. Jamison, V. C. Chemical relationships of potassium and magnesium in organic and sandy soils of Central Florida. Soil Sci. 61: 443-453. 1946.
7. MacIntire, W. H., W. H. Shaw, B. Robinson and J. B. Young. Potassium retention from annual additions of chloride, sulfate and nitrate, as influenced by limestone and dolomite. Soil Sci. 55: 321-332. 1943.
8. Morgan, M. F. Soil changes resulting from nitrogenous fertilization. A lysimeter study. Connecticut Agr. Expt. Sta. Bul. 384. 1936.
9. Pearson, R. W. Liming and fertilizer efficiency. Agron. Jour. 50: 356-362. 1958.
10. Peech, M. Availability of ions in light sandy soils as affected by soil reaction. Soil Sci. 55: 37-48. 1943.
11. Peech, M. Chemical studies on soils from Florida citrus groves. Florida Agr. Expt. Sta. Bul. 448. 1948.
12. Spencer, W. F. Influence of cation-exchange reactions on retention and availability of cations in sandy soils. Soil Sci. 77: 129-136. 1954.
13. Thomas, G. W. and N. T. Coleman. A chromatography approach to the leaching of fertilizer salts in soils. Soil Sci. Soc. Amer. Proc. 23: 113-116. 1959.
14. Truog, E. and R. J. Jones. Fate of soluble potash applied to soils. Ind. and Eng. Chem. 30: 882-885. 1938.
15. Volk, G. M. and C. E. Bell. Soil reaction. Florida Agr. Expt. Sta. Bul. 400. 1944.
16. Volk, G. M. and C. E. Bell. Some major factors in the leaching of calcium, potassium, sulfur and nitrogen from sandy soils. Florida Agr. Expt. Sta. Bul. 416. 1945.

The Effects of Particle Size and Rate of Solution on The Availability of Potassium Materials.[1]

W. L. PRITCHETT AND C. N. NOLAN[2]

The soils of Florida are generally highly leached and extremely low in potassium reserves. The use of relatively large applications of potassium fertilizer is essential for the production of most agricultural crops. To meet the needs of crops, the equivalent of approximately 129,000 tons of K_20 were applied to Florida soils during the 1959-60 crop year. Although annual applications of 300 to 600 pounds of K_20 per acre are not uncommon on highly fertilized crops, such as celery, a large part of the applied potash may be eventually leached as soluble salts in the soil solution.

The use of slowly soluble potassium fertilizers has been suggested as a means of increasing the efficiency of fertilizer materials by reducing leaching losses, luxury consumption, and salt injury to plants. Potassium products prepared by fusing orthoclase feldspars with KCl or KNO_3, which dissolved slowly in water but furnished adequate quantities of potassium to plants when applied to soils, have been used successfully for ornamentals (3, 5).

The Tennessee Valley Authority has produced a number of fused potassium phosphate materials varying in rate of solution from 5 to 95%. The rate of solution, as used herein, is the percentage of the potassium in a material that dissolves when 1 gm. of the material is agitated in 250 ml. of water for one hour at room temperature (1). These materials are of two general types: those derived from potassium metaphosphate (KPO_3) and those made from potassium-calcium pyrophosphate ($K_2CaP_20_7$). The materials are fused at about 1650 F and the rate of solution of the compounds is affected by the presence of small amounts of iron oxide, alumina and silica and by the rate of cooling of the melt (1, 4). In short-term greenhouse experiments, crop yields obtained from the use of potassium sources of slow water solubility have usually been no different from yields obtained with muriate (KCl) or sulfate (K_2SO_4) of potash. These latter two sources dissolve rapidly in water and are widely used in fertilizers. DeMent and Stanford (1) reported that availability to corn of potassium ranging in rate of solution from 4 to 100% was not related to this property of the materials. The fused potassium phosphates supplied as much potassium to corn during three successive cropping periods of 7, 6 and 7 weeks as did KCl and K_2SO_4. The absence of leaching in most greenhouse experiments may explain why the efficiency of fused potassium has generally been as good, but no better, than that of ordinary potassium materials. In a Wisconsin field experiment (2), conducted on relatively fine textured soil where potassium leaching was not a problem, rate of solubility of various potassium materials apparently had little effect on corn yields.

Generally a portion of the potassium in the fused potassium materials

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[3]Materials supplied by Division of Chemical Development of the Tennessee Valley Authority, Wilson Dam, Alabama.

dissolves rather rapidly in water and the remainder slowly. For example, in a material derived from potassium metaphosphate 12% of the K_2O dissolved in one hour, 16% in one week, 35% in one month and 87% in six months (1, 4). However, they apparently become available in the soil sufficiently rapid to supply potassium needs of most crops. In a preliminary laboratory experiment, fused potassium-calcium pyrophosphate was added to sterilized and non-sterilized Arredondo fine sand and incubated for 40 days. Ammonium acetate extractable potassium in subsamples was determined at regular intervals. There were no significant differences in the amounts of extractable potassium in the sterilized and non-sterilized soil, indicating that soil microorganisms had little influence on the dissolution of the material.

While results of limited tests with slowly-soluble potassium materials have been generally disappointing, they were mostly preliminary experiments and were not conducted on sandy soil under high rainfall conditions, where leaching may take place, such as encountered in Florida. The purpose of these experiments was to check the relative availability of several sources of potassium varying in rate of solution and particle size in controlled experiments in greenhouse lysimeters.

METHOD OF PROCEDURE

Three successive greenhouse experiments were conducted with potassium materials varying in rate of solution and particle size. Particles were grouped into −35, −6+14, and −3/8"+4 mesh sizes. Materials of various particle sizes were supplied by T.V.A.,[3] except the large particles of KCl. The latter was made by pressing white KCl at 15,000 psi. and then breaking the cake into large particles and screening to the correct size.

The first experiment was conducted with coastal bermudagrass in three different soils in greenhouse pots to check the effect of three sources of potash, each of two particle sizes, on forage yields. The materials were KCl and fused KPO_3 and $K_2CaP_2O_7$ with 100, 9 and 7% of the potassium in water-soluble form, respectively. The particle sizes were −35 mesh and −6+14 mesh, as shown in Table 1.

Three soils, Lakeland sand, Arredondo loamy fine sand and Ruston fine sandy loam, were placed in 2 gallon glazed pots and planted to coastal Bermudagrass. The soils contained 11, 11 and 118 ppm. of ammonium acetate (pH 4.8) extractable K, respectively. The potassium materials were surface applied to soils at the rate of 166 ppm. of K (equivalent to 400 pounds K_2O per acre) after the grass was established. Nitrogen, as ammonium nitrate, was added uniformly to all pots at the rate of 50 ppm. initially and after each harvest. Phosphorus, as mono-calcium phosphate, was added to all pots that did not receive the potassium phosphates, in amounts to result in equal phosphate applications to all pots. The pots were watered as required for good growth, but no leaching was permitted. Four cuttings were taken at regular intervals over a period of approximately one year.

The second experiment was a short-term study conducted in 2-gallon greenhouse lysimeters in which KCl, KPO_3, $K_2CaP_2O_7$ and K_2SO_4 were applied to oats at rates of 41 and 82 ppm. of K (equivalent to 100 and 200 pounds of K_2O per acre). The KCl and K_2SO_4 materials were 100%

TABLE 1.—TOTAL POTASSIUM UPTAKE (GM. PER POT) IN 4 CUTTINGS OF COASTAL BERMUDA-GRASS ON 3 SOIL TYPES FERTILIZED WITH VARIOUS SOURCES OF POTASSIUM AT THE RATE OF 200 POUNDS OF K_2O PER ACRE.

	Percent of K Soluble*	Mesh	Lakeland sand	Arredondo l.f.s.	Ruston f.s.l.	Ave.
KCl	100	−35	1.537	1.525	2.276	1.779
KCl	100	−6+14	1.154	1.484	2.174	1.604
KPO_3 (fused)	13	−35	1.654	1.522	2.032	1.736
KPO_3 (fused)	13	−6+14	1.473	1.465	2.175	1.704
$K_2CaP_2O_7$ (fused)	7	−35	1.568	1.380	2.057	1.668
$K_2CaP_2O_7$ (fused)	7	−6+14	1.332	1.334	1.984	1.553
Average for Soil Type			1.453	1.452	2.116	

*Percent K dissolved after agitating 1 g. of material in 250 ml. of water for 1 hour at room temperature.

water soluble while the potassium in the fused KPO_3 and $K_2CaP_2O_7$ was 13 and 7 % water soluble, respectively. Previous work had indicated that particle size had little influence on the availability of soluble materials, but that the availability of materials of low water solubility was decreased with increasing particle size. For this reason the large mesh size of fused KPO_3 and $K_2CaP_2O_7$ was used. A high grade (50% K_2O) "granular" K_2SO_4, manufactured by the Hargrove process, was included since it was suspected of being less available than ordinary crystalline K_2SO_4. Treatments are given in Table 2.

TABLE 2.—YIELD OF OATS AND POTASSIUM RECOVERY IN FORAGE AND LEACHATE FROM VARIOUS POTASSIUM SOURCES IN THE GREENHOUSE.

K Sources	Particle Size	Percent of K Soluble*	K Applied mg. /pot	Dry wt. of oats, grams per pot 1st cutting	2nd cutting	K recovered from soil and fertilizer, mg. per pot leachate	forage
KCl	−6 +14	100	310	12.3	11.2	36.3	335
KCl	−6 +14	100	620	14.3	9.8	76.9	474
KPO_3 (fused)	−¾″+4	13	310	12.7	10.8	8.7	301
KPO_3 (fused)	−¾″+4	13	620	15.3	9.4	16.7	417
$K_2CaP_2O_7$ (fused)	−¾″+4	7	310	12.0	9.4	12.1	257
$K_2CaP_2O_7$ (fused)	−¾″+4	7	620	15.0	8.9	23.6	392
K_2SO_4	Gran.	100	310	14.1	10.1	36.0	335
K_2SO_4	Gran.	100	620	15.7	9.3	80.0	516
K_2SO_4	Cryst.	100	310	12.7	9.0	33.8	291
K_2SO_4	Cryst.	100	620	14.7	10.6	92.4	459

*Percent of K dissolved after agitating 1 gm. of the material in 250 ml. of water for 1 hour at room temperature.

The potassium materials and uniform applications of 100 ppm. of nitrogen (N) and phosphorus (P_2O_5) were mixed with the upper three inches of Lakeland fine sand and planted to Floriland oats. One week prior to the first harvest of oats the soils were leached with 2500 ml. water (approximately 2.5 acre-inches) and then they were leached a second time with 2500 ml. of water at time of harvest. Only the second leachates were analyzed for potassium content. Approximately four months after planting a second (final) harvest of oats was made.

The third experiment was conducted with three sources of potassium of varying water solubility and particle size applied at the rate of 82 ppm. to Arredondo fine sand in 3-gallon greenhouse lysimeters. This soil had an initial exchange capacity of 7.5 me. per 100 g. and contained 15 ppm. of ammonium acetate (pH 4.8) extractable K. The potassium in the KCl and fused KPO_3 and $K_2CaP_2O_7$ was 100, 13 and 7% water soluble, respectively. The materials were applied in each of the following particle sizes: −35, −6+14, and −3/8″+4 mesh. The potash materials, along with basic applications of 200 pounds per acre of nitrogen and phosphorus were mixed with the upper three inches of soil and millet was planted. Three weeks after the initiation of the experiment, and at monthly intervals thereafter, all soils were leached with deionized water. A total of 18 liters of water (equivalent to about 16 acre-inches) was collected from each treatment and the leachate analyzed for potassium. Approximately 1, 2 and 4 months after planting, harvests of millet forage were made. During the following winter months, oats were grown in the lysimeters without additional potassium treatments, although additional uniform applications of nitrogen and phosphorus were added as considered necessary for good growth. The oat forage was cut twice and the lysimeters again planted to millet the following summer. The millet forage was harvested twice. Forage from each of the seven harvests of oats and millet was oven dried, weighed and analyzed for potassium content.

After the last harvest of oats, all soils were again leached twice with 3300 ml. of distilled water; each leaching was equivalent to a total of 6 acre-inches. The volume of leachates were measured and analyzed for potassium content.

RESULTS AND DISCUSSION

In the first experiment, the yields of 4 cuttings of coastal Bermudagrass, fertilized at the rate of 400 pounds of K_2O per acre, were not significantly different among the 3 sources of potassium of varying water solubility. However, the yields obtained from the −6+14 mesh particles were generally less than yields obtained from the −35 mesh particles, regardless of water solubility. The potassium uptake in the forage followed the same general pattern, as shown in Table 1. There were no significant differences in potassium uptake among sources (water solubility) in this short-term greenhouse experiment, although, uptake of potassium from the larger particles (−6+14 mesh) was significantly less than from the smaller particles (-35 mesh). These data agree with results of greenhouse studies reported by DeMent and Stanford (4). The uptake of potassium was significantly greater from the finer textured Ruston soil than from the two sands. The former soil contained a

substantially greater amount of available soil potassium than the latter soils.

It is apparent that the materials of low water solubility become available in soil sufficiently rapid to supply the needs of the grass and at a rate not greatly different from that of KCl. Since no leaching was permitted in this experiment, any reduction in potassium movement due to the decrease in water solubility of the materials was not determined. The decrease in potassium uptake from the larger particles was probably due to lower rate of dissolution in the soil—even though the rate of solution in water of the large particles was equal to that of the finer particles of the same material.

In the second experiment, there were no differences in the amounts of potossium leached among the three soluble sources. Although the leaching losses from the two materials of low water solubility were significantly lower than from the water soluble materials, they were not significantly different from each other.

Forage yields of the first harvest, made shortly after the soils were leached, increased from an average of 12.7 g. per pot for the low rate of application (100 pounds of K_2O per acre) to 15.0 gr. for the high rate of application (200 pounds of K_2O per acre). However, there were no differences among sources of potassium. In the second harvest, yields from the low rate of application were generally as great as from the high rate of application. However, after the second harvest, the soils were sieved in order to recover the undissolved particles of the slowly-soluble materials. As much as 50% of the fused $K_2CaP_2O_7$ was recovered and 20 to 40% of the fused KPO_3 was undissolved.

Yields of the two harvests of oats were essentially as great from the materials of low water solubility as those from the soluble materials, although there was less leaching of potassium from the former materials and a considerable portion of the slowly soluble materials remained for potential use of future crops. The third experiment was established with materials of different particle sizes and solubility and conducted over a longer period under more intensive leaching conditions in an attempt to recover this unused portion of the slowly soluble materials.

In the third experiment the movement of potassium during the preharvest leaching of pots was rather drastically affected by both water solubility and particle size of the materials (Table 3). Leaching losses of the soluble materials (KCl) were much greater than from the less soluble materials. Losses increased with increases in particle size of the soluble materials but for materials of low water solubility, losses generally decreased with increased particle size. There was practically no loss of potassium from any source during the post-harvest leaching with approximately 6 acre-inches of water.

The yields of the 3 harvests of the first millet crop, 2 harvests of oats and 2 harvests of the second millet crop are given in Table 3. It should be remembered that only an initial application of potassium materials, equivalent to 200 pounds of K_2O per acre, was made. There were no significant differences in yields of the first millet crop due to sources of potassium. Even the yields of the oat crop were not significantly different, although yields resulting from the slowly soluble materials and the larger particles were somewhat greater than from the soluble materials and small particles. However, yields of the third crop (second millet

TABLE 3.—YIELDS OF THREE FORAGE CROPS AND RECOVERIES OF POTASSIUM FROM SOURCES VARYING IN PARTICLE SIZE AND WATER SOLUBILITY IN GREENHOUSE EXPERIMENTS.

POTASSIUM TREATMENTS*				Millet (3 harvests)		Oats (2 harvests)		Millet (2 harvests)		K recovered in leachates		Total
No.	Source	Percent of K Soluble**	Particle Size	Dry wt. g.	K uptake gm.	Dry g. wt.	K uptake mg.	Dry wt. g.	K uptake mg.	pre-harvest mg.	post harvest mg.	K recovered mg.
1.	KCl	100	−35	39.4	664.4	16.0	52.3	16.8	65.0	146.4	3.1	931
2.	KCl	100	−6 +14	41.8	642.8	18.7	65.1	16.2	63.8	144.3	7.4	923
3.	KCl	100	−3/8″+4	37.7	705.1	18.9	74.0	21.4	79.4	236.2	3.2	1097
4.	KPO_3 (fused)	13	−35	40.3	664.4	18.4	62.4	21.1	80.1	74.1	3.2	884
5.	KPO_3 (fused)	13	−6 +14	42.6	681.7	19.6	81.2	16.2	61.4	77.9	4.0	906
6.	KPO_3 (fused)	13	−3/8″+4	38.5	440.8	25.1	212.7	57.2	301.6	52.6	5.2	1013
7.	$K_2CaP_2O_7$ (fused)	7	−35	42.5	728.4	18.6	59.4	15.2	59.4	55.8	6.4	909
8.	$K_2CaP_2O_7$ (fused)	7	6 +14	42.8	627.3	25.3	114.9	33.4	118.4	48.2	5.9	915
9.	$K_2CaP_2O_7$ (fused)	7	−3/8″+4	41.5	507.2	23.8	111.9	28.9	114.7	46.9	3.8	784
10.	Soil (no K added)			27.0	115.8	10.6	30.7	3	38.2	29.3	5.1	219

*All posassium sources applied at rate of 798 mg. per pot (200 pounds K_2O per acre).

**Percent of K issolved after agitating 1 g. of material in 250 ml. of water for 1 hour at room temperature.

crop) were drastically influenced by the residual potassium contained in the larger (-3/8 inch + 4 mesh) particles. Figure 1 shows the gradual decline in yields in pots receiving an application of KCl, but the rather uniform yields from the 3 crops produced in pots receiving the larger particles of fused KPO_3 and $K_2CaP_2O_7$.

The percent recoveries of applied potassium fertilizers in each of the 3 crops and 2 leaching periods are given in Figure 2. Percent recovery was calculated by substracting the potassium removed in the harvests or leachings of the check (no potassium added) pots from that removed from pots receiving the various materials. The apparent total removal of more fertilizer potassium than was added as the −3/8 inch + 4 mesh KCl was the result of larger leaching losses of soil potassium from the pots containing this material than from those which received no fertilizer potassium.

SUMMARY

The effect of rate of solution and particle size of several potassium materials, including fused KPO_3 and $K_2CaP_2O_7$ of low water solubility, on the availability of potassium to crops was studied in three greenhouse experiments. The first two tests were conventional greenhouse experiments, while the third involved 3 successive small grain crops in lysimeters.

Availability of potossium was not related to water solubility of materials of less than 35 mesh. The finely divided materials of low water solubility apparently became available at a sufficiently rapid rate in the soil to supply potassium to the plant in equivalent amounts to that from ordinary soluble sources (KCl and K_2SO_4).

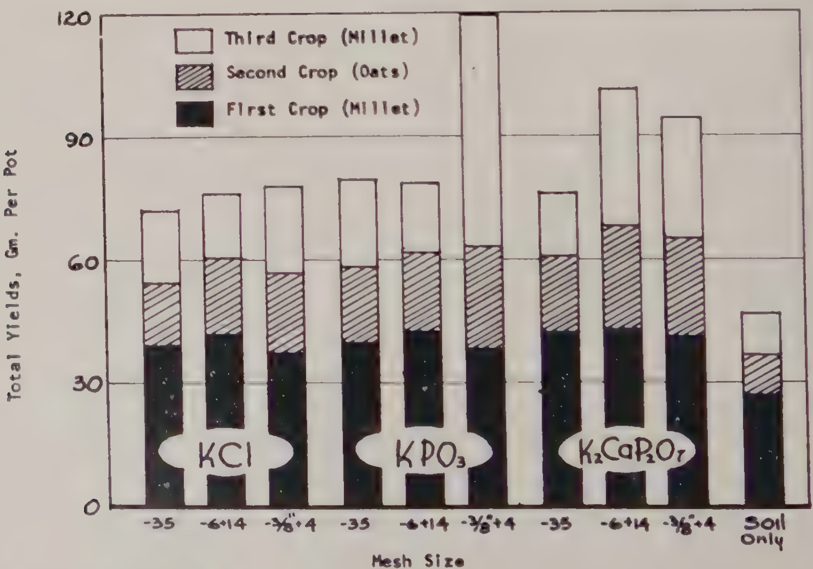

Fig. 1. The yields of three successive grain crops receiving one application of 200 pounds of K_2O per acre from sources varying in water solubility and particle size.

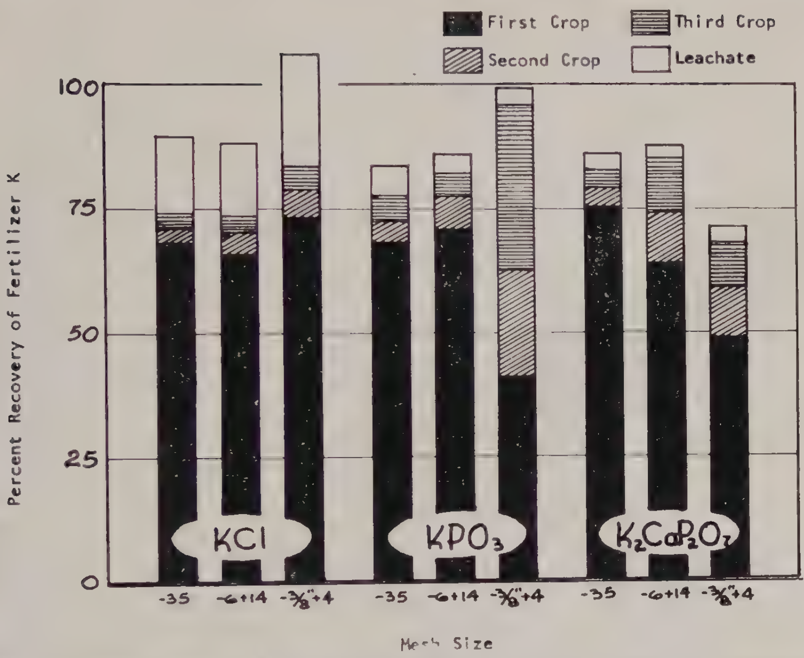

Fig. 2.—Percent recovery of fertilizer potassium, varying solubility and fertilizer size, in three grain crops and in the leachates.

On the other hand, increasing the size of the particle of the potassium materials to -6 + 14 mesh and -3/8" + 4 mesh had a decided effect on the availability and leaching of potassium in sandy soils. In a short term experiment, where no leaching was permitted, increasing the particle size decreased the crop yield and potassium uptake from soluble materials, as well as those of low water solubility. In the relatively long-term greenhouse lysimeter experiment, leaching losses of potassium from KCl were about 3½ times that from the slowly soluble sources. Increasing the particle size of KCl to —3/8"+4 mesh increased yields slightly but increased leaching losses almost 100 percent over that from the slowly soluble sources. Leaching from the slowly soluble sources generally decreased with increasing particle size, although losses of potassium from these materials were small regardless of particle size. Yields of the 3 crops increased as the size of the particles increased. This was particularly true of the slowly soluble materials, where the slower rate of availability resulted in rather uniform yields for the 3 successive crops.

LITERATURE CITED

1. DeMent, J. D. and G. Stanford. Potassium availability of fused potassium phosphates. Agron. Jour. 51:282-285. 1959.
2. Kline, J. R. and A. C. Caldwell. Potassium solubility has little bearing on crop yields. Crops and Soils 12 (2):24. 1959.
3. Lunt, O. R. and B. Kwate. Potassium frit as a special purpose fertilizer. Soil Sci. 82:3-8. 1956.
4. Stanford, G. and T. P. Hignett. Fertilizer development in the TVA: New processes and agronomic implications. Soil and Crop Sci. Soc. Fla. Proc. 17:161-185. 1957.
5. Woltz, S. S. Nitrogen and potassium fertilization of potted chrysanthemums. Fla. State Hort. Soc. Proc. 70:346-350. 1957.

Magnesium Content of Pecan Leaves as Influenced by Seasonal Rainfall and Soil Type[1]

NATHAN GAMMON, JR., KEITH D. BUTSON AND RALPH H. SHARPE[2]

Typical leaf symptoms of magnesium deficiency of pecans are of relatively rare occurence under the usual cultural practices; however, they are sometimes found on excessively drained, coarse sandy soils. During the course of the routine leaf analysis of pecan leaf samples taken in September of 1958, from a number of nutritional experiments in North Florida, it was noted that the level of magnesium in many of the samples was in the deficiency range (7). A careful check eliminated the possibility of analytical errors (8), differences in size of the crop or responses to different fertilizer programs as possible causes for the relatively low magnesium levels. Leaf analysis from previous years were examined and it was noted that magnesium results obtained in 1953 were also relatively low. A check of weather records indicated that 1953 and 1958 were years of above average rainfall for the sampled areas. Hence, the possible correlation between low magnesium levels in the pecan leaves and years of heavier than average rainfall became the basis for this study.

The tendency for plants to exhibit high magnesium levels under conditions of restricted moisture (4, 6, 9) and low levels during wet seasons (1) has been reported.

EXPERIMENTAL

A considerable number of leaf analysis for magnesium, taken over a period of three to eight years, were available but it was found that the number that could be used in an unbiased comparison was limited. All values which included fertilizer treatments likely to have a major effect on the leaf level of magnesium were omitted. Likewise, data from trees located more than a few miles from weather stations or involving changes in analytical procedures for different years were omitted. Preliminary studies of this information showed that variety differences were rather large (3, 8) so that analysis of different varieties in a single orchard could not be combined. Magnesium levels in leaves from different orchards often showed wide variations so that a combination of data from nearby orchards was seldom practicable. The degree of fluctuation of the magnesium level in the leaves varied with soil type so that samples from the same orchard could not be used if they were not taken consistently from the same location. Data from the same tree or group of trees, i. e. check trees in fertilizer experiments sampled in a number of successive years, were especially sought. Despite the above limitations it was possible to draw useful data from 22 locations representing all major soil types used for pecan production in the Eastern half of the Florida pecan belt. These locations included a total of 8 pecan varieties and provided anna-

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lytical data over periods of from 3 to 7 years. Data representing the longest periods of time and the most common varieties, Curtis and Stuart, were subjected to the most detailed statistical analysis to determine the effect of rainfall on the level of magnesium in the pecan leaves.

Simple graphs were plotted and correlation statistics determined for the relationship between magnesium level in the leaves and local rainfall pattern. The data were treated in several ways in an effort to find the most critical response periods. Correlations were made between leaf magnesium and annual rainfall, and for rainfall of certain shorter periods in the year. Likewise soil moisture conditions were estimated, using Thornthwaite and Mather's (10) potential evapotranspiration procedure in conjunction with the approximate characteristics of the soil type involved, to determine periods when the soil moisture levels would be expected to be in excess of requirements, adequate or limiting. "Surplus" rainfall was determined by using monthly average temperatures and monthly total rainfall at nearby weather stations. Possible relationships between magnesium and levels of other minerals in the leaves, e.g. Ca:Mg ratios, were also investigated.

RESULTS AND DISCUSSION

The most consistent correlations were found between the magnesium levels in pecan leaves sampled in September and the amounts of "surplus" rainfall during the preceding January through May period. Typical data are presented in Figure 1. Since the slope of the relation between surplus rainfall and magnesium levels was found to be negative in all cases and many of the relations approached the 0.01 level of significance, it is concluded that the magnesium content in Florida pecan leaves in September is associated with the surplus rainfall occurring during the preceding January through May period.

Other time periods and calculations based on total rainfall, total days of surplus soil moisture or total days of drought were correlated with the percentage Mg in the leaves as well as with Ca:Mg ratios and they produced some correlation values (r) of higher significance for one location or condition. However, all the individual pools of data examined produced significant correlations most consistently when the total surplus rainfall for the January through May period was employed. These variations are not surprising when all the differences in amount, frequency and distribution of rainfall that occur from year to year are considered. The important fact is that despite varietal differences, location differences and a variation in soils, there is a generalized correlation of leaf magnesium with rainfall which is applicable to a wide variety of conditions.

Hunter and Hammer (3) reported that the percent of magnesium in the leaves of pecans sampled in early June was practically the same as that found in trees resampled in September of the same year but that the concentration of other elements varied widely between June and September samplings. Our limited observations tend to confirm these findings. Evidently magnesium uptake by the roots takes place largely in the spring months. This explains the relation between spring moisture conditions and levels of magnesium in the leaves.

Poor aeration, associated with high soil moisture, may reduce the ability of roots to absorb magnesium. It was generally observed that

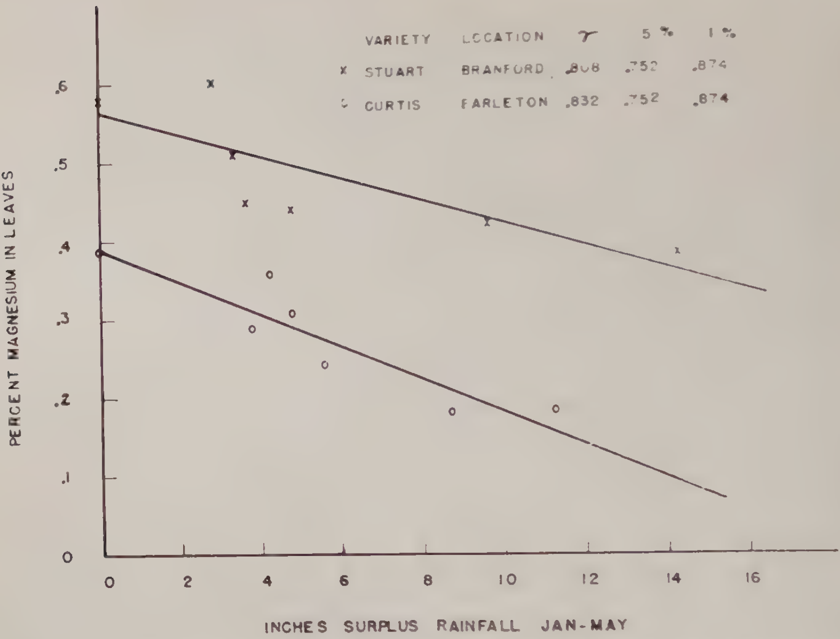

Fig. 1.—Relationship between surplus rainfall and the magnesium level in pecan leaves.

absorption of potassium was reduced more by poor aeration than was the uptake of nitrogen, calcium, magnesium or phosphorus (5). If poor aeration alone was the cause of low magnesium values, a reduction in the level of potassium and these other elements would also be expected. Likewise the effect of poor aeration should be more pronounced on Rex fine sand with its relatively poor internal drainage than on Norfolk fine sand with its good to excessive drainage. Since such differences were not noted it is probable that some factors other than aeration are influencing the magnesium level in the pecan leaves.

In reviewing the soil characteristics it was noted that the ratio of exchangeable calcium to magnesium decreases with depth for all the soils included in this study (2). A typical soil profile analysis is shown in Table 1.

Extensive studies of pecan root systems by Woodroof (11) and Woodroof and Woodroof (12) show conclusively the effects of soil moisture on the development of pecan feeder roots. They found that feeder roots were killed by drought or prolonged water-logging. In the spring, feeder roots initiated a rapid growth considerably earlier than leaf development. They showed that when moisture conditions were favorable the general direction of feeder root growth was upward. The Woodroofs also estimated that under Georgia conditions of alternate wetting and drying there could be as many as 5 to 7 cycles of feeder root development within a single year. Similar conditions could be expected in Florida.

In general, pecan feeder roots will develop most extensively in the area of most favorable soil moisture. During the spring months, the Ca:Mg ratio in the soil in which the feeder roots are most active will

TABLE 1.—EXCHANGEABLE CALCIUM AND MAGNESIUM IN A VIRGIN REX FINE SAND PROFILE.

Horizon Depth	Ca	Mg	Ca/Mg Ratio
Inches	me/100 g.	me/100 g.	
0- 2	1.02	0.33	3.09
2- 6	.35	.11	3.18
6-12	.18	.10	1.80
12-18	.15	.16	.94
18-24	.25	.31	.81
24-32	.26	.47	.51
32-42+	.16	.56	.29
	(Typical pecan orchard, unlimed)		
0- 6	1.14	.31	3.64
	(Typical pecan orchard, limed)		
0- 6	2.17	.25	8.67

be a major factor in determining the magnesium level in the leaves. Abundant rainfall tends to favor longer periods of favorable soil moisture near the surface, resulting in maximum root development in that area and a low level of leaf magnesium, while deficient rainfall results in a droughty surface soil and a tendency toward more root development at greater depths. Apparently this results in higher levels of leaf magnesium.

SUMMARY AND CONCLUSIONS

In many pecan groves in Florida the magnesium level in the leaves decreases with increasing amounts of rainfall during the late winter and early spring months. This correlation is attributed to the effect of fluctuations in depth of major feeder root activity associated with soil moisture supply on soil types characterized by decreasing Ca:Mg ratios with increasing soil depth.

Pecan producers in the eastern section of the pecan belt have long held that the nature of the weather during the preceding season had a strong influence on the pecan crop. While no correlations with crop production were attempted here, it is apparent that amount and distribution of rainfall can cause rather large fluctuations in the magnesium nutrition of pecan trees.

LITERATURE CITED

1. Davidson, O. W. Nutrient-deficiency symptoms in decidous fruits. Hunger Signs in Crops, Grove Hambridge, Editor, Am. Soc. Agron. and Nat. Fert. Assoc., Pub. 1941.
2. Gammon, Nathan, Jr., J. R. Henderson, R. A. Carrigan, R. E. Caldwell, R. G. Leighty and F. B. Smith. Physical, spectrographic and chemical analyses of some virgin Florida soils. Fla. Agri. Expt. Sta. Tech. Bul. 521 Aug. 1953.
3. Hunter, J. H. and H. E. Hammar. Variation in composition of pecan leaves. Better Crops 41 No. 2:1825 Feb. 1957.
4. Janes, B. E. The effect of varying amounts of irrigation on the composition of two varieties of snap beans. Proc. Am. Soc. Hort. Sci., 51:457. 1948.

5. Lawton, K. The influence of soil aeration on the growth and absorption of nutrients by corn plants. Soil Sci. Soc. Am. Proc. 10:263. 1945.
6. McMurtrey, J. E., Jr., J. D. Bowling, D. E. Brown and H. B. Engle. Effects of controlled soil moisture on growth, composition, yield and quality of Maryland tobacco. J. Agri. Research 75:215. 1947.
7. Sharpe, R. H., G. H. Blackmon and Nathan Gammon, Jr. Magnesium deficiency of pecans. Proc. Southeastern Pecan Growers Assoc. 44:23-28. 1951.
8. Sharpe, R. H. and Nathan Gammon, Jr. Sources of error in foliar analysis of pecans. Proc. Am. Soc. Hort. Sci. 58:120-124. 1951.
9. Thomas, W., W. B. Mack and R. H. Cotton Foliar diagnosis in relation to irrigation. Proc. Am. Soc. Hort. Sci. 40:531. 1942.
10. Thornthwaite, C. W. and J. R. Mather. The Water Balance. Drexel Inst. of Technology, Lab. of Climatology, Centerton, N. J. Publication in Climatology Vol. 8 No. 1 pg. 103. 1955.
11. Woodroof, J. G. The relation of root system of pecan trees to nursery and orchard practices. Georgia Agr. Expt. Sta. Bul. 176. 1933.
12. Woodroof, J. G. and Naome C. Woodroof. Pecan root development. J. Agri. Research 49:511-530. 1934.

Retention of Fertilizer Elements in Red Bay Fine Sandy Loam[1]

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Successful soil management requires a knowledge of the soil characteristics as well as a knowledge of what happens to the fertilizer elements after they have been applied to the soil. The retention, leaching, and availability of applied elements will depend to a large extent on the amounts and kinds of clay minerals in the soil. These will vary with soil type.

The experiment from which the material for this paper was obtained was conducted on a soil typical of those used for general farming in North and West Florida. The experiment has been in progress for 8 years and is still active. Results for the first 4 years have been described previously (5, 10). This paper is confined to 8 years soil data.

METHODS

The experiment was located on an area of Red Bay fine sandy loam which had been recently cleared from pine forest and had grown one lightly fertilized small grain crop. The soil is well-drained with a sandy clay substrate at 20 to 40 inches below the surface. The surface soil is dark brown to reddish brown and contains approximately 70% sand, 19% silt and 11% clay. The zone of maximum clay content, red to yellowish red, occurs 20 to 40 inches below the surface and contains about 63% sand, 14% silt and 23% clay.

The experiment consisted of two series of adjacent plots. A two-year rotation of lupines plowed down for corn the first year and oats plowed down for peanuts the second year was carried out on each series. In series 1 the rotation started with peanuts and in series 2 corn; thus all crops

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appeared every year. The treatments for each series consisted of a complete factorial of 5 levels each of N, P_2O_5 and K_2O and 2 levels of dolomitic limestone. A split plot design with one replication per series was used with dolomitic limestone being applied as the subplot treatment in two increments 2000 lbs. per acre in 1950 and 4000 lbs. additional in 1952.

The experiment was initiated in 1950. In 1955 series 2 was modified. The fertilizer treatments were not repeated but cropping was continued. This was done to test residual effects of the fertilizers. In 1956 series 1 was modified; corn was replanted instead of peanuts and then planted again in 1957. However, fertilizer treatments were made each year as before.

Levels of the various nutrients applied annually to the corn and peanuts are shown in the footnote of Table 1. Ammonium nitrate, ordinary super-phosphate and muriate of potash were the sources of N, P and K, respectively.

Corn grain and cobs were removed from the corn plots. Peanut vines and nuts were taken from the peanut plots.

Samples were taken from 0-6″ deep from at least 34 plots in each series every year before fertilization. The plots selected were the limed and unlimed halves of treatments receiving the following ratios of N, P_2O_5 and K_2O: 0-0-0, 15-30-15, 30-60-30, 60-120-60, 120-240-120, 0-240-120, 15-240-120, 30-240-120, 60-240-120, 120-0-120, 120-30-120, 120-60-120, 120-120-120, 120-240-0, 120-240-15, 120-240-30 and 120-240-60. Profiles were taken to a depth of 36 inches by blocks before the experiment was established in 1950 and on the 34 plots listed above in 1955. Samples were taken from 0-6″ depth from all plots in series 2 in 1955 and all plots in series 1 in 1956 and 1958.

TABLE 1.—pH VALUES AT END OF EIGHT YEARS AS AFFECTED BY LIME AND ANNUAL FERTILIZER TREATMENTS.

Level*	N		P		K	
	Lime	No Lime	Lime	No Lime	Lime	No Lime
	pH values**					
1	5.8	5.0	5.6	4.8	5.7	5.0
2	5.8	5.1	5.6	4.9	5.6	4.9
3	5.6	5.0	5.6	4.9	5.6	5.0
4	5.5	5.0	5.7	5.0	5.7	5.0
5	5.5	4.7	5.7	5.1	5.6	5.0

*N and K_2O treatments corresponding to these levels were 0, 15, 30, 60 and 120 lbs/A. P_2O_5 treatments were double these.

**Each value is an average of a factorial of 5 levels of the other two elements or 25 values.

Statistical Summary

Nitrogen and phosphorus sig. at 0.01
Lime sig. at 0.01
Lime times nitrogen sig. at 0.05

The soils were analyzed for organic matter by the Walkley-Black method (12). Exchangeable calcium, potassium and magnesium were extracted with ammonium acetate at pH 4.7. The calcium and potassium were determined using the Beckman DU flame spectrophotometer and magnesium was determined colorimetrically using sodium polyacrylate to stabilize the color (7, 2). Total potash was determined using Gammon's modification of the J. L. Smith method (4). Total phosphosphorus was determined by the Bray and Kurtz method (1). Available phorus (9) was extracted with 0.3 N NH_4F in 0.1 N NHCl, using 10 parts extractant to 1 part soil (1). Subsequent extractions on the soil samples with NH_4F, Na OH, H_2SO_4, sodium dithionite plus sodium citrate, NH_4F and Na OH removed according to the method of Chang and Jackson (3) free $AlPO_4$, free $FePO_4$, $Ca_3(PO_4)_2$, reductant $FePO_4$ occluded $AlPO_4$ and occluded $FePO_4$, respectively.

RESULTS AND DISCUSSION

Liming and pH:

The exchangeable calcium varied with the pH. The virgin soil had a pH of 5.2 and contained 300 pounds of exchangeable calcium per acre. One ton of dolomitic lime increased the pH to 5.6 and the exchangeable calcium to 500 pounds per acre. Two additional tons increased the pH to 6.2 and the exchangeable calcium to approximately 900 pounds per acre. Each of the above values represent average of 125 plots. Soil samples were taken 2 years after the lime application. Cropping reduced the exchangeable calcium and pH.

Data in Table 1 show the effect of N, P, K, and lime on pH. Nitrogen in the form of ammonium nitrate depressed the pH. Superphosphate tended to increase the pH. This could be expected since superphosphate supplies approximately one pound of calcium for every pound of P_2O_5. In the 8 years prior to sampling, a total of 240, 480, 960, and 1920 pounds per acre of P_2O_5 conforming to phosphorus levels 2, 3, 4, and 5, respectively had been applied.

The effect of 8-years fertilization with nitrogen, phosphorus and potassium on the exchangeable calcium is given in Table 2. Increased rates of nitrogen decreased the available calcium in the limed and unlimed soil. The effect appeared to be greater on the unlimed soils than on the limed soils. Increased rates of phosphorus increased the exchangeable calcium. As previously pointed out, 0 to 1920 pounds of calcium per acre depending on the superphosphate application had been applied over the 8-year period.

Profile analysis showed that calcium movement was small. There was usually more calcium in the subsoil when the soils were limed than when the soils were unlimed. Increasing the fertility level increased the calcium in the surface soil, because of the calcium in the superphosphate. Generally this was associated with higher levels of calcium in the subsoil.

Magnesium determinations were not made on all samples. Magnesium in the unlimed soil was low, approximately 30 pounds per acre. The level in the limed soils was approximately 200 pounds per acre in 1955, 1956 and 1957. This was after the plots received a total of 3 tons of dolomitic lime.

TABLE 2.—EFFECT OF LIME AND ANNUAL APPLICATIONS OF FERTILIZER ON THE EXCHANGEABLE CALCIUM AFTER 8 YEARS.

Level*	N		P		K	
	Lime	No Lime	Lime	No Lime	Lime	No Lime
	Exchangeable calcium in lbs./A.**					
1	540	170	400	60	510	140
2	560	150	420	80	550	120
3	520	140	520	130	560	140
4	520	150	580	170	530	140
5	490	90	940	250	520	150

*N and K_2O treatments corresponding to these levels were 0, 15, 30, 60 and 120 lbs./A. P_2O_5 treatments double these.

**Figures represent 25 plots, being a factorial of 5 levels each of the other two elements.

Statistical Summary

Phosphorus sig. at 0.01
Lime sig. at 0.01
Lime times nitrogen sig. at 0.05
Lime times phosphorus sig. at 0.01

Organic Matter:

There was no measureable annual variation in the organic matter. The organic matter averaged approximately 3%. Soil samples taken after 5 and 8 years showed that nitrogen, phosphorus and potassium had no significant effect on the level of organic matter.

Potassium:

Data in Table 3 show that practically none of the residual potassium could be accounted for in the exchangeable form in the top 6 inches. In 1951 the level was 119 and in 1958 it was 120 pounds of K_2O per acre. Liming improved the retention of potassium by 36 pounds of K_2O per

TABLE 3.—EFFECT OF LIME AND TIME ON THE EXCHANGEABLE POTASSIUM IN THE SURFACE 6 INCHES.

	1951	1952	1953	1954	1955	1956	1957	1958	Ave.
	Exchangeable K_2O in pounds per acre*								
Lime	126	127	225	164	240	272	220	135	189
No lime	112	108	189	130	205	190	185	105	153
Average	119	118	207	147	222	231	202	120	171
	Inches								
Annual Rainfall**	67	50	82	35	51	59	72		

*Each value is an average of 17 plots.

**Soil samples were taken in January hence the rainfall affecting the potassium would be that recorded for the previous year.

acre on an 8-year average. In some years the exchangeable potassium was higher than others. This variation was seldom more than the applied potassium for one year. The potassium levels should be correlated with the previous year's rainfall since samples were taken in January. When the annual rainfall was less than 60 inches, 54 inches being the average for the area, applied potassium remained in the surface 6 inches. When it was more than 60 inches most of the residual potassium was unaccounted for in the exchangeable form. The rainfall pattern or the number of leaching rains was also an important factor.

Total potassium was determined on the samples taken from the plots where potassium was varied and nitrogen and phosphorus were at the 5th level to see if the potassium unaccounted for might still be in the surface soil but not in the exchangeable form. Results were not conclusive. The average K_2O content of the untreated soil was 3000 pounds per acre and the sampling error was usually more than the difference needed to account for the unused fertilizer potash not in the exchangeable form in the top 6 inches.

TABLE 4.—MOVEMENT OF POTASH TO A DEPTH OF 36 INCHES AFTER FOUR YEARS FERTILIZATION.

	Annual Treatments*				
Depth	0-0-0	15-30-15	30-60-30	60-120-60	120-240-120
	Exchangeable K_2O in lbs./A.				
0-6″	82	94	103	115	158
6-12″	36	34	43	48	86
12-24″	38	29	29	43	70
24-36″	36	29	31	36	67
	Gain or loss from top 36″				
Total to top 36″	266	244	266	321	518
Change due to applied K		−22	0	65	252
Applied 4 years	0	60	120	240	480
Loss**		−88	−120	−175	−228

*Ratios indicate the pounds per acre of N, P_2O_5 and K_2O applied annually.

**Does not take into account crop removal.

The possibility that the potassium moved down in the profile was investigated after 4 years cropping. Samples were taken to a depth of 36 inches because it was felt that this would still be in the root zone of most crops. The samples were taken following a year of above normal rainfall so movement of potassium would be exaggerated. Data are reported for five general rates of fertility in Table 4. Values can be compared with those for the unfertilized treatment. Potassium moved out of the surface only at the highest two levels of fertility. The lower half of Table 4 shows the gain or loss of potassium from the top 36 inches of the profile. These calculations do not take into consideration the potassium removed by the crop. A crop of peanuts yielding a ton of nuts per acre removes from the soil 50 lbs. per acre K_2O (8) and a corn crop yielding 83 bushels removes approximately 16 lbs. per acre (6). Using these figures and extrapolating for yields obtained it was believed that roughly 20 pounds per acre of K_2O per year was removed

by the crops. This meant that 22 to 35% of the potash was unaccounted for at the three highest levels of fertilization.

The 1955, 1956 and 1958 data in Table 5 shows the effect of the fertilizer elements on the level of exchangeable potassium in the top six inches. Nitrogen applied as ammonium nitrate and phosphorus as superphosphate had no consistent effect of the level of exchangeable potassium, but it increased progressively with rates of applied muriate of potash.

Phosphorus:

Data to show the effect of fertilization and cropping on phosphorus levels in the soil are presented in Table 6. The lower half of the table shows that practically all of the applied phosphorus can be accounted for in the top six inches. Crop removal (6, 8) and sampling errors would account for the gain or loss. The higher values in the 6-12 inch layer at the higher application rate were probably due to mixing in the plowing operation.

Phosphorus was extracted from all soil samples with acid ammonium fluoride. Previous work on limed soils indicated that this extractant removed a portion of the phosphorus that correlated with the available phosphorus (11). In this study it was found that .03N NHF in 0.1N HCl removed on the average 159 pounds of P_2O_5 per acre less from the limed soils than the unlimed soils. Furthermore the maximum amount of phosphorus removed by the extractant was approximately 600 pounds of P_2O_5 per acre on the limed soils and 840 pounds of P_2O_5 per acre on the unlimed soils even though there was a continued increase of total phosphorus in the soil. However, these levels are beyond those necessary for maximum corn yields (approximately 370 pounds of P_2O_5 per acre (5)).

Repeated application of phosphorus on this soil even at rates of 120 pounds per acre of P_2O_5 gave yield responses. However, yield data have shown that the residual fertilizer phosphorus was more available than the original soil phosphorus (5). Fractionation studies following the

TABLE 5.—EFFECT OF FERTILIZATION ON EXCHANGEABLE POTASSIUM IN THE SURFACE 6 INCHES.

Level*	1955 N	1955 P	1955 K	1956 N	1956 P	1956 K	1958 N	1958 P	1958 K
	K_2O in lbs./A.**								
1	174	159	110	132	142	88	74	97	40
2	166	162	136	140	133	108	73	74	56
3	172	172	160	132	136	126	71	69	70
4	171	167	199	142	134	165	76	66	99
5	164	182	243	138	139	204	75	63	114

*N and K_2O treatments corresponding to these levels were 0, 15, 30, 60 and 120 lbs./A., P_2O_5 treatments were double those of N and K_2O.

**Figures are averages of 50 values being a factorial of 5 levels each of the other two elements and 2 levels of lime.

TABLE 6.—MOVEMENT OF PHOSPHORUS TO A DEPTH OF 36 INCHES AFTER FOUR YEARS FERTILIZATION.

Depth	0-0-0	15-30-15	Treatment* 30-60-30	60-120-60	120-240-120	Ave.
			Total P_2O_5 (lbs./A.)			
0-6″	710	900	960	1140	1640	1070
6-12″	600	600	630	630	690	630
12-24″	500	620	520	430	440	502
24-36″	540	710	600	550	510	582
			Balance sheet			
Increase 0-6″		190	250	430	930	360
Applied	0	120	240	480	960	360
Gain or Loss**		70	10	−50	−60	0

*Ratios indicate the pounds per acre of N, P_2O_5 and K_2O applied annually.
**Does not take into consideration crop removal.

methods of Chang and Jackson (3) were carried out to determine in what chemical form residual fertilizer phosphorus occurred. For this study samples were selected to show what effect fertilizer, lime and cropping had on the various fractions. Table 7 shows the order of magnitude of the phosphorus compounds over a 4-year period. They are averages of 5 rates of fertility and 2 levels of lime. Liming and fertilizing had no consistant effect on the water-soluble phosphorus, occluded aluminum and iron phosphate, reductant iron phosphate and calcium phosphate. Rates of phosphorus affected the levels of free aluminum and iron phosphates as shown by data recorded in Table 8. It is apparent from these data that more fertilizer phosphorus went into the aluminum phosphate form than into the iron phosphate form. Subtracting values obtained for the zero phosphate treatment (120-0-120) from those obtained for the highest phosphate treatment (120-240-120) for 1958 gives 780 pounds per acre of P_2O_5 as aluminum phasphate and 386 pounds per acre as $FePO_4$ or a ratio of 2 to 1.

Data obtained from series 2 samples are shown in Table 9. The

TABLE 7.—EFFECT OF TIME ON FORMS OF PHOSPHORUS AS DETERMINED BY THE METHOD OF CHANG AND JACKSON (3).

Year	Water Soluble	$AlPO_4$ Free	$AlPO_4$ Occluded	$FePO_4$ Free	$FePO_4$ Occluded	$FePO_4$ Reductant	$Ca_3(PO_4)_2$
					P_2O_5 in lbs./A.*		
1951	9	112	35	158	34	697	105
1955	8	295	49	282	37	733	127
1957	7	281	21	255	0	687	48
1958	13	335	36	279	36	687	119

*Figures are averages of 10 plots.

TABLE 8.—EFFECT OF FERTILIZATION AND TIME ON LEVEL OF $AlPO_4$* AND $FePO_4$*.

Annual Fertilization**	$AlPO_4$*				$FePo_4$*			
	1951	1955	1957	1958	1951	1955	1957	1958
	P_2O_5 in lbs./A.***							
120- 0-120	73	103	92	68	97	172	172	172
120- 30-120	110	154	137	151	143	212	172	215
120- 60-120	102	202	160	149	154	212	172	172
120-120-120	114	321	412	458	192	326	286	286
120-240-120	176	696	607	848	215	489	475	558

*NH_4F and NaOH extracted $AlPO_4$ and $FePO_4$ respectively according to Chang and Jackson.

**Ratios indicate the pounds per acre of N, P_2O_5 and K_2O applied annually.

***Values are averages of limed and unlimed plots.

samples were from treatments where phosphorus application were terminated in 1955 and cropping was continued to 1958. The data indicates that aluminum phosphate was decreasing while the iron phosphate remained relatively constant. The values in Table 10 are single determinations. A laboratory experiment showed somewhat similar aluminum: iron phosphate relationship and it was concluded that the aluminum phosphate was converted to iron phosphate with time (13).

SUMMARY

An experiment testing 5 rates each of nitrogen, phosphorus and potash and 2 rates of lime on corn and peanuts grown in rotation on Red Bay fine sandy loam was sampled annually for 8 years.

A ton of dolomitic lime increased the exchangeable calcium approximately 200 pounds per acre. Cropping with a 2-year rotation of corn and peanuts used up this much in about 5 years.

Three tons of dolomitic lime were required to raise the pH from

TABLE 9.—EFFECT OF FERTILIZER AND TIME ON ACCUMULATION OF $ALPO_4$* AND $FEPO_4$*

Annual Fertilization**	$AlPO_4$*		$FePO_4$*	
	1955	1958	1955	1958
	P_2O_5 in lbs./A.			
120- 0-120	103	52	172	97
120- 30-120	137	69	172	97
120- 60-120	160	103	218	286
120-120-120	275	189	246	218
120-240-120	607	378	332	332
Ave.	256	158	228	215

*NH_4F and NaOH extracted $AlPO_4$ and $FePO_4$ respectively according to Chang and Jackson.

**Ratios indicate the pounds per acre of N, P_2O_5 and K_2O applied annually.

5.2 to 6.2. Organic matter was maintained at approximately 3% over the 8-year period. When potash was applied at rates of 30, 60 and 120 pounds per acre of K_2O annually, 20 to 35% of it could not be accounted for in the top 36 inches after four years. The exchangeable potash in the surface 6 inches fluctuated with the annual rainfall.

Fertilizer phosphorus remained in the surface 6 inches. Fractionation studies showed that it was converted to free aluminum and iron phosphates in the ratio 2 to 1. In the 8-year period occluded and reductant forms of aluminum and iron phosphates were relatively constant. When cropped without additional phosphorus, the aluminum phosphorus decreased while the iron phosphorus was constant.

ACKNOWLEDGMENTS

The authors are indebted to Mr. H. L. Carver for his assistance in the chemical analysis.

LITERATURE CITED

1. Bray, R. H. and L. T. Kurtz. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59: 39. 1945.
2. Carver, H. L. and W. K. Robertson. A study of some laboratory methods for determining calcium and magnesium. Soil and Crop Sci. Soc. of Fla. Proc. 16: 258-271. 1956.
3. Chang, S. C. and M. L. Jackson. Fractionation of soil phosphorus. Soil Sci. 84: 133-144. 1957.
4. Gammon, Nathan, Jr. Determination of total potassium and sodium in sandy soils by flame photometer. Soil Sci. 71:211. 1951.
5. Hutton, C. E., W. K. Robertson and W. D. Hanson. Crop response to different soil fertility levels in a 5 by 5 by 5 by 2 factorial experiment: 1 corn. Soil Sci. Soc. of Amer. Proc. 20: 531-537. 1956.
6. Jordon, H. V., K. D. Laird and D. D. Ferguson. Growth rates and nutrient uptake by corn in a fertilizer-spacing experiment. Agron. Jour. 42: 261. 1950.
7. Mehlich, A. Improvements in colorimetric magnesium and ammonium methods with sodium polyacrylate. A. O. A. C. 518-523. 1956.
8. Romaine, J. D. When fertilizing, consider plant food content of crops. Better Crops with Plant Food. 24 (3): 6 and 37. 1940.
9. Robertson, W. K. and C. E. Hutton. Relation between phosphorus recovered by plants and that removed by chemical extractants from Florida soils. Soil Sci. Soc. of Fla. Proc. 13: 149-159. 1953.
10. Robertson, W. K., C. E. Hutton and W. D. Hanson. Crop response to different soil fertility levels in a 5 by 5 by 5 by 2 factorial experiment: 2 peanuts. Soil Sci. Soc. of Amer. Proc. 20: 537-543. 1956.
11. Robertson, W. K., J. R. Neller and F. D. Bartlett. Effect of lime on the availability of phosphorus in soils of high to low sesquioxide content. Soil Sci. Soc. of Amer. Proc. 18: 184-187. 1954.
12. Walkley, A. An examination of methods for determining organic carbon and nitrogen in soils. Jour. Agr. Sci. 25: 598. 1935.
13. Yuan, T. L., W. K. Robertson and J. R. Neller. Forms of newly fixed phosphorus in three acid sandy soils. Soil Sci. Am. Proc. 24: 1960.

Soil and Plant Nutrition Research in Costa Rica 1958-60

ALBERT E. KRETSCHMER, JR.[1]

INTRODUCTION

The writer was assigned to Costa Rica to act as consultant in the STICA Laboratory. For a more detailed account of the physical plant of the laboratory and the previous research work accomplished the reader is referred to the paper presented by Dr. Gaylord M. Volk[2]. During the writers assignment there were many changes in laboratory and other techniques with the advent of sufficient greenhouse space and the installation of a macro-kjeldahl. A summary of the accomplishments achieved at the laboratory is presented under several headings.

GREENHOUSE

For the first time, a greenhouse was used extensively for various nutritional studies. Some of this experimental work was conducted with nutrient solutions, including one experiment to determine the deficiency symptoms manifested by the coffee plant when grown in the absence of particular elements. Deficiencies of iron, calcium, phosphorus, sulphur, nitrogen, magnesium, manganese, potassium, and boron were produced, and chemical analysis of leaves for all of the above named elements were made to obtain some indication of deficiency levels in the plant.

Another solution culture experiment was designed to determine the quantity of nitrogen in the plant necessary for maximum growth. In this greenhouse experiment coffee plants were grown for about a year. Chemical analyses for nitrate and protein nitrogen are being made to determine the concentration correlated with maximum plant growth, and to determine which part of the plant is the best indicator for changes in the nitrogen content of the substrate.

Several experiments with soils were completed including one to determine the potassium supplying power and another to determine the phosphorus supplying power of different soils collected from various farming areas in Costa Rica.

Results obtained from the nutrient solution and soils studies were extremely informative indicating that greenhouse methods are very applicable in solving many of the soil and plant nutritional problems in Costa Rica. Such experiments are easily accessible to the various technicians located in San Jose, whether they be commercial or government employees. For example, there was a great deal of interest by the various commercial and government technicians in the experiment with the deficiency symptoms with coffee. Several people came to the laboratory

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[2]Volk, Gaylord M. 1958. Florida's contributions to agronomic development in Central America 1. Soils Research in Costa Rica. Soil and Crop Sci. Soc. Fla. Proc. 18:22-30.

almost every week to examine the various deficient plants, in an effort to obtain a better understanding of the deficiencies.

LABORATORY

In most instances the greenhouse experiments were augmented by chemical analyses in the laboratory. In this manner a more thorough evaluation of the results was obtained.

At the present time soil and plant samples are analyzed for nitrogen, potassium, iron, phosphorus, calcium, magnesium, boron, manganese, sulphur and molybdenum. In addition, pH, organic matter content and exchange capacity of soils are being determined when necessary. Also, procedures have been developed to permit fractionating the various soil phosphorus compounds. The results of these analyses benefit the people in the laboratory directly in their research programs and are of much value to farmers, research personnel in other projects, and to commercial technicians with fertilizer companies. Soil analysis results have led to the publication of several articles dealing with the chemical characterization of the soils of Costa Rica. With the techniques already developed and with the possibility of future analyses, a chemical analysis soil-survey of the major agricultural producing areas of the country can be made.

FIELD EXPERIMENTS

Field experimental work is conducted by the laboratory in cooperating farmers' fields or at the University of Costa Rica's farm. Results of such field experiments have been very rewarding during the last two years. For example, one experiment with coffee plants indicated that phosphorus applications below the soil surface were much more satisfactory than were surface applications. In a field experiment supplemented by one in the greenhouse the effectiveness of spray applications of 10 percent sugar in water solutions was proved very effective in preventing the wilting and death of young coffee plants when transplanted to the field. Also, leaf and soil analyses are being used in conjunction with fertility tests in the field in an effort to determine the optimum fertility levels for the coffee plant with better accuracy.

RESEARCH WORK

Two of the research projects conducted during the writer's assignment in Costa Rica made use of both the greenhouse and laboratory facilities, and will have a direct bearing on the overall knowledge of the fertility status of Costa Rican soils. Each is briefly discussed as examples of the type of work conducted at the laboratory.

Potassium.—Fourteen different virgin soils having widely different physical characteristics were collected from the field, brought into the greenhouse and placed in pots, where they were fertilized with all essential elements except potassium. Pangolagrass was planted to determine which soils were deficient in potash. Pangolagrass was used as an indicator crop because it has a rather large requirement for potassium and grows rapidly after each cutting. This experiment was continued for almost a year during which time 11 cuttings were made. In conjunction with the greenhouse phase, portions of each soil were treated with seven potassium extracting

solutions in an effort to find one that would be suitable for the majority of the soil types in Costa Rica. The soil potassium contents were compared with the quantity absorbed by the grass, and with grass yields. The chemical method previously used by the laboratory for potassium extractions proved very satisfactory (neutral normal ammonium acetate). Using this extractant, soil analyses were made periodically at harvest time. It was determined that when the soil potassium level fell below 100 pounds per acre a deficiency of this element in the pangolagrass was very likely to occur. Below 80 pounds, there was always a visual manifestation of the deficiency in the grass during the next regrowth after cutting. A majority of the soils tested had sufficient potash reserves to produce several crops of pangolagrass. One rather striking result was that there was no evident connection between the potassium supplying power of the soil and its parent material or origin. Results of this experiment gave information that is an invaluable aid in making fertilizer recommendations and in the chemical characterization of the soils of Costa Rica.

Phosphorus.—Costa Rican soils vary greatly in their content of clay materials. Some contain large quantities of montmorrilonite while others contain large amounts of kaolinite or illite. The difference in organic matter and calcium contents, and iron and aluminum oxide contents are extreme. A partial chemical analysis of representative soils used are presented in Table 1. All of these properties affect the ability of soils to fix phosphorus or release phosphorus to plants. Because there was almost no information concerning phosphorus fertilization, an extensive greenhouse experiment was initiated to determine: (1) the phosphorus fixing capacities and phosphorus availability of virgin Costa Rican soils, (2) the various forms of phosphorus in these soils, (3) plant growth responses to fertilizer phosphorus, (4) the chemical methods for extracting phosphorus from soils that would give a good indication of the phosphorus availability to plants, and (5) the relationships between soil extractable phosphorus, plant phosphorus contents and plant yields. The replicated experiment conducted under the direction of Lic. Alejandro Acevedo, was designed to utilize 20 previously unfertilized and different soil types located within the major coffee growing areas of Costa Rica; the Meseta Central, the area near Tilaran, and the southern area of Costa Rica near San Vito de Java. All soils were fertilized with adequate quantities of the essential elements except phosphorus, and then each soil was divided into four separate parts, each receiving rates of 0, 60, 120 and 180 pounds of P_2O_5 per acre supplied as KH_2PO_4. The soils, after being placed into containers were planted to Criollo sorghum. Two similar experiments were initiated using coffee seedlings and red clover as the indicator plants. In total, therefore, each of 20 soils received four different rates of phosphorus fertilizer upon which were grown three different plant species.

Yield data from the three plants have been obtained and much of the chemical analytical data for the soils have been completed. Only a very brief summary of the results will be presented here. For a more detailed report the termination of assignment report by Kretschmer is available.[3]

[3]Kretschmer, Jr., Albert E. 1960. Resume of work accomplished at the Laboratorio Quimico de Investigaciones Agronomicas. Projecto 30, STICA and MAI. San Jose, Costa Rica.

TABLE 1.—A PARTIAL CHEMICAL ANALYSES OF THE COSTA RICAN SOILS USED IN THE PHOSPHORUS EXPERIMENT

Soil			pH	Exchange Capacity	Organic Matter	R_2O_3	Exchangeable[4] Ca	Exchangeable[4] Mg	Exchangeable[4] K	Total[5] Ca	Total[5] Mg	Total[5] K
No.	Name	Type		me./100 gm.	%	%	ppm	ppm	ppm	ppm	ppm	ppm
1.	Turrialba	L[1]	5.0	25.8	5.6	40.9	304	88	110	1540	1120	440
2.	Turrialba	A[2]	5.2	30.7	3.2	30.0	1836	554	220	3240	3850	1350
3.	Granadilla	V[3]	5.9	31.1	10.0	18.0	1040	594	1244	2800	5460	1600
4.	San Josecito	V	5.9	33.0	3.1	23.9	2850	282	1460	1740	1330	1810
5.	Heredia	V	5.4	29.6	7.1	32.3	298	66	219	1200	960	980
6.	San Fernando	L	5.7	33.3	6.7	34.7	780	294	144	1700	1540	280
7.	Tilaran	A	5.5	19.4	5.6	13.9	2170	210	355	54600	11140	1800
8.	San Vito	A	5.5	42.0	11.1	19.2	298	115	73	3120	2690	100
9.	San Vito	L	5.0	19.8	0.8	28.9	166	122	31	860	860	

[1]Lateritic
[2]Alluvial or alluvial-colluvial
[3]Volcanic
[4]Extracted 50 grams of soil with 500 ml. neutral normal ammonium acetate.
[5]Totals to nearest 10 pounds, obtained by digestion of soils with perchloric acid.

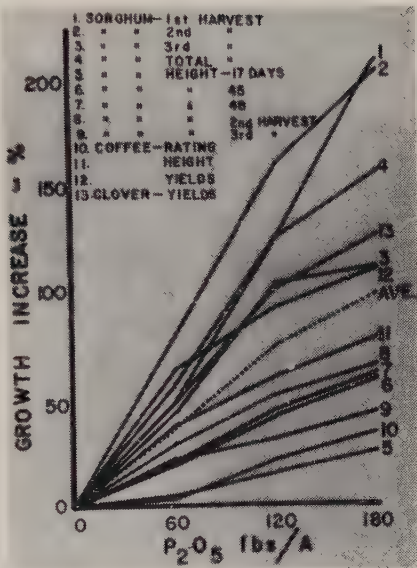

Fig. 1.—Percent increase in various growth measurements resulting from different rates of phosphorus fertilization as KH_2PO_4 to 20 virgin Costa Rican Soils.

Some of the results obtained were as follows: (1) Coffee seedlings, sorghum, and red clover responded very well to additions of phosphorus to 180 pounds of P_2O_5 per acre on about one-half of the soils tested. On the remaining soils responses were poor even at the 180-pound rate. This indicated extremely high fixing capacities or possible excesses of some toxic element such as aluminum. None of the soil pH values were extremely low, but preliminary evidence indicated that certain of the soils had large phosphorus fixation capacities. (2) The overall response to phosphorus when soils were averaged was outstanding, as evidenced in Figure 1 where positive responses were obtained for all measurements. Sorghum responses at the first cutting were almost a direct function of the quantity of P_2O_5 applied while for coffee there was a larger growth response from the 0 to 60-pound rate than from the 60 to 120 or 120 to 180-pound rates. The average response for all measurements combined was a straight line function of the phosphorus rate up to the 120-pound level. (3) Significant positive correlations were obtained between growth of any two of the three plant species indicating that relative growth differences were similar regardless of soils or treatments. (4) Soils having low contents of calcium and, or, high iron and aluminum oxide contents generally were those that produced small plants and to which there were few or no responses to phosphorus.

To determine the cause of this poor growth on certain soils two preliminary experiments were made using sorghum planted on the lateritic soil from San Vito (No. 9). Height measurements of sorghum from these tests are presented in Table 2. The first test (left of Table 2) showed that there was a definite response to both phosphorus and lime, even though the phosphorus response was at very high levels. The second test confirmed the first, indicating that it would be possible to grow satisfactory crops only if considerable lime and phosphorus were added. The best growth of sorghum, for example, was made where 1,500 pounds of P_2O_5 and 4000 pounds of lime per acre were used.

TABLE 2.—THE EFFECTS OF DIFFERENT LIME AND PHOSPHORUS RATES ON THE HEIGHTS OF SORGHUM GROWN ON A LATERITIC SOIL.

Material—Rate/Acre	Height—Inches	Material—Rate/Acre	($-CaCO_3$)	($+CaCO_3$ —4000)[2]
1. P_2O_5[1]—120	2	1. P_2O_5[1]—100	2	4
2. P_2O_5—240	2	2. P_2O_5—500	2	6
3. P_2O_5—1,320	8	3. P_2O_5—1,000	2	7
4. P_2O_5—48 + $CaCO_3$—4,000	7	4. P_2O_5—1,500	3	10
		5. P_2O_5—3,000	6	9

[1]As KH_2PO_4
[2]Chemically pure calcium carbonate at a rate of 4000 pounds per acre.

COOPERATION

Because of its position with respect to other projects in the field of agriculture, the laboratory has had the opportunity to co-operate with a number of the different agencies in Costa Rica. Explanations of the current work in the greenhouse and in the laboratory were made to many visiting commercial and government technicians and farmers. There was direct cooperation between the laboratory and various other projects and agencies by means of chemical analysis and research reports. In 1959 the number of plant and soil samples that were analyzed chemically for the various projects were as follows: *Plant analyses*—Project 23 (Coffee)—352; Inter-American Institute of Agricultural Sciences—1000; samples from farmers and commerciaal technicians—781; *Soil samples*—Project 29 (Pastures)—94, Project 23 (Coffee)—39, Project 22 (Cacao)—15, Project 10 (Irrigation)—47, Inter-American Institute of Agricultural Sciences—41, samples from farmers and commercial technicians—245. About 2500 soil and plant samples were submitted for analyses during 1959 and about 7000 individual chemical analyses were completed.

PUBLICATIONS

In the three years the laboratory has been functioning in the new building on the University of Costa Rica's campus, it has been possible to develop an intensive research program. Although it is difficult to evaluate the benefits derived from this program in so short an interval, some insight can be gained through a knowledge of the published accomplishments to date. The following is a list of bulletins and mimeographed papers published at the completion of certain phases of the research work conducted at the laboratory during Dr. Volk's and the author's assignments to Costa Rica. The information was available to all of the extension agents and technicians in Costa Rica and some of the information was sent to the major coffee growing areas in Latin America.

1. Gil Chaverii, Elmer Bornemiza and Francisco Chaves. Resultados del Analisis Foliar del Cafeto en Costa Rica. MAI (Ministry of Agriculture and Industries and STICA Informacion Tecnica No. 3, 1957. Information is given concerning the mineral contents of coffee leaves as

affected by seasonal variations and the leaf position on the plant. Comparisons are made with other coffee producing countries.

2. Ana Mercedes Ramos Lopez. Influencis de Lixiviacion de Aniones en Perdidas por Arrastre de Cationes. MAI and STICA Informacion Tecnica No. 6, 1958. This bulletin shows the effects of adding various cations to the soil on the leaching of anions.

3. Gil Chaverri and Francisco Carvajal. Sintomas de Deficiencia de los Alimentos Fosfora, Calcio, Azufre y Hierro en el Cafeto Producidos en Invernadero. MAI and STICA Informacion Tecnica No. 8, 1959. Information given in this bulletin has already been of immense value to farmers and technical people by presenting a clear picture of the various visual symptoms of deficiencies that may appear when there is a lack of one of the nutrient elements studied. This work has shown that the "so-called" calcium deficiency reported numerous times to occur in the field was not actually a calcium deficiency, but the result of some other physiological disturbance. Now, recommendations to use lime (an expensive material) in many such instances can be stopped.

4. Francisco Carvajal. Nutricion Mineral del Cafeto, Requerimientos de la Cosecha. MAI and STICA Informacion Tecnica No. 9. 1959. This bulletin provides information concerning the quantity of fertilizer materials contained in the coffee bean and in the coffee pulp. Using these data farmers and technicians are able to calculate the quantity of the nutrient elements that are removed yearly with each crop and thereby have an idea of the nutrient needs of the plants for the following year. Also the fertilizer value of the coffee pulp that is put back on the soil can be calculated.

5. Elmer Bornemiza. Sulphur Categories in the Soils of the Meseta Central of Costa Rica. MAI and STICA Informe poligrafiado 59-1, 1959. This work with 11 different soil types shows the different amounts of sulphur that might be found in similar soils. Results indicated that most of these soils contained sufficient sulphur to support maximum growth. This would indicate that a farmer would not feel required to use ammonium sulfate as a source of nitrogen (and sulphur), but could use a much cheaper source such as urea.

7. Francisco Carvajal and Francisco Pereira. Atomizaciones con Azucar Envitan la Marchitez Cuando se Transplanta el Cafe. MAI and STICA. Informe poligrafiade 59-3, 1959. The effectiveness of the laboratory in accomplishing "practical" research is demonstrated here. When one year old coffee seedlings are transplanted from seedling beds to the field the death of plants due to the shock of transplating sometimes is rather large particularly when rainfall is inadequate. The preliminary results of spraying plants prior to transplanting with a 10% sugar water solution were excellent by markedly reducing the death of transplanted seedlings.

8. Alejandro Acevedo. Velocidad de Hidrolisis de la Urea y el Biuret en Algunos Suelos de Costa Rica. Thesis, Department of Chemistry, University of Costa Rica, 1959. This study was made because of the commercial damage to coffee plants produced by the chemical compound, biuret, that was contained in the nitrogen fertilizer, urea. It has answered many of the practical questions dealing with the subject, such as how long the harmful effect of biuret might persist in certain soils.

9. Orlando Bravo. Metodos Quimicos para Determinar el Poder Suministrador de Potasio de los Suelos. Thesis, Department of Chemistry, University of Costa Rica, 1959. A summary of these results was presented under the title of *Potassium*.

10. Francisco Pereira. Arsenic Contents in Leaves and Fruits of Coffee Plants as Affected by Different Spray Applications Containing Arsenic. Thesis, Department of Agronomy, University of Costa Rica. 1960. Arsenic is being used commercially to control a fungus disease on coffee. Pertinent information is presented concerning the arsenic contents of leaves, fruit and beans from coffee plants with arsenic solutions. There does not appear to be any serious build-up of arsenic in the bean even when rather high spray concentrations are used.

11. Elmer Bornemiza. Acides, Potassio y Materia Organica de Algunos Suelos de Costa Rica. MAI and STICA. This is a survey type report giving typical pH, potassium and organic matter values of various soils of Costa Rica.

12. Laboratorio Quimico de Investigaciones Agronomicas. Annual Report 1958.

13. Laboratorio Quimico de Investigaciones. Annual Report 1959. These Annual Reports concerning work at the laboratory are very comprehensive, giving a brief summary of all the work conducted during the year.

CONCLUSION

The laboratory was transferred to the University of Costa Rica on November 1, 1960 and will receive some outside financial assistance during the next several years. Its future depends upon the desire of the University of Costa Rica to aid the agricultural interests of the country. The soils and plant physiological problems are numerous and experimental work should be continued at a rapid pace to permit the overall agricultural growth to progress.

The writer wishes to express his appreciation to personnel of the laboratory for their cooperation at all times, and especially wishes to thank Ing. J. Francisco Carvajal, Lic. Alejando Acevedo and Ing. Gil Chaverri who were responsible for making the laboratory function smoothly as a unit.

Effect of Flatwoods Pasture Fertilization on Soil Test Results[1]

C. L. DANTZMAN, E. M. HODGES AND W. G. KIRK[2]

The first improved pastures were established at the Range Cattle Station in 1942. Since then numerous fertilizer treatments have been practiced for different periods of time. These pastures, located on Immokalee, Leon and Ona fine sands, afforded an opportunity to determine the effects of various fertilization practices on the supply of plant nutrients in the soil. From 3 to 6 pastures having similar fertilization were grouped into treatments. Table 1 shows yearly application of fertilizer and lime for 7 treatments described in the following series:

1. Native pasture: Cutover pine land, with wiregrasses furnishing a majority of the feed. Cattle were grazed rotationally throughout the year. No soil amendments were applied.
2. Native pasture plus rock phosphate: A single application of 2,000 pounds finely ground raw rock was made in 1946. The areas were heavily chopped at time of fertilization and seeded to carpetgrass. Grazing was the same as for Treatment 1.

TABLE 1.—PASTURE AND YEARS OF TREATMENT WITH AVERAGE ANNUAL APPLICATION OF FERTILIZER ELEMENTS.

Pasture Treatment	Years of Treatment	Number of Pastures	Annual Average Treatment in Pounds Per Acre				
			N	P_2O_5	K_2O	CaO	MgO
1. Native	..	6	0	0	0	0	0
2. Native + rock P.	14	4	0	47	0	66	0
3. Impr. grass	4	4	95	30	30	140	120[1]
4. Impr. grass	7	3	95	30	30	133	68[1]
5. Impr. grass	14	6	62	30	30	193	34[1]
6. Hairy indigo-grass	11	5	0	57	50	213	22[1]
7. Whiteclover-grass	15	5	8	87	93	345	40[1]

[1]Some MgO in fertilizer filler.

3. Improved grass—4 years: Pastures were fertilized twice yearly, once in spring and again in late summer or fall, applications of 500 pounds per acre of 9-6-6 fertilizer and 150 pounds ammonium nitrate being alternated. Initial applications of copper were made to all grass plantings, with some manganese and zinc being added. Retreatment has consisted of 0-1 unit CuO equivalent spaced 5 years apard. Calcic or dolomitic lime was applied on grass pastures at 2,000 pounds per acre at 4- to 6-year intervals. Grazing of all pangolagrass pastures was conducted on a rotational basis.

[1]Florida Agricultural Experiment Station Journal Series, No. 1216.
[2]Assistant Soils Chemist, Agronomist and Vice-Director in Charge, respectively, Range Cattle Experiment Station, Ona, Florida.

4. Improved grass—7 years: Pastures were fertilized and managed on the same basis as Treatment 3 but covered a longer period of time.
5. Improved grass—14 years: This treatment included the oldest pastures on the Range Cattle Station. Grass fertilization prior to 1950 was based largely on a single annual application of 500 pounds per acre of 6-6-6. Fertilization during the years following 1950 paralleled that described for Treatment 3.
6. Hairy indigo-grass: This summer legume was grown with different grasses and grazed most intensively during September and October. The residual nitrogen improved grazing values of grass through the following April and May. Annual spring treatment with 0-14-10 at 450 pounds per acre was practiced until 1954 when use of 0-8-24 at 300 pounds per acre was begun. Lime was necessary for Hairy indigo on flatwoods soils and was applied at 2,000 pounds per acre at 3- to 5-year intervals.
7. Whiteclover-grass: All but one of these pastures were irrigated by either sprinkler or seepage systems. Fertilization through the year 1953 consisted of a fall application of 0-14-10 at 500 pounds per acre. This was changed in 1954 to 1 or 2 applications of 250 pounds of 0-8-24 with additional muriate of potash in most years. Clover plantings received copper, manganese, zinc and boron at time of establishment. Retreatment with copper consisted of 0.1 unit CuO equivalent per acre at 5- to 7-year intervals. Additional boron was applied but not on a regular basis. Initial lime treatment for clover totalled 4,000 pounds per acre or more. Reliming was done at 3- to 5-year intervals at the 2,000-pound rate. All clover pastures were heavily grazed on a rotational basis, being left ungrazed in late fall and early winter when the new clover crop was allowed to establish.

METHOD OF MEASUREMENT

Each pasture was sampled in the spring seasons of 1959 and 1960 by taking 20 soil cores to a depth of 6 inches. The samples were sieved through a 2 mm screen, extracted with 1 normal ammonium acetate of pH 4.80 and analyzed according to the methods described by Breland.[3,4]

RESULTS

Pastures of similar management practices were grouped and the data averaged. Soil test results of available plant nutrients in pounds per acre are given in Table 2. The low nitrogen values are routine since sandy soils accumulate little available nitrogen and grass sods have a high removal capacity. All values for native pastures with the exception of MgO were low, this being entirely normal for untreated flatwoods land. The P_2O_5 and CaO levels obtained on native pastures plus rock phosphate treatment were 89% and 126%, respectively, above those of the untreated area, showing the effects of the calcium and phosphorus added. It is a matter of considerable interest that these soil analyses clearly reflect the influence of a single soil treatment after a lapse of 14 years.

[3]Breland, H. L. Department of Soils Mimeo Report No. 58-3, Nov. 6, 1956.
[4]Cooperation with Soil Testing Laboratory, University of Florida, Gainesville.

TABLE 2.—AVAILABLE FERTILIZER ELEMENTS PER ACRE.

Pasture Treatment	Years of Treatment	Number of Pastures	Soil Test Results[1] Available Pounds Per Acre NO$_3$	P$_2$O$_5$	K$_2$O	CaO	MgO	pH
1. Native	....	6	VL[2]	9	40	434	129	4.7
2. Native + Rock P.	14	4	VL	17	41	981	127	4.7
3. Impr. grass	4	4	VL	21	66	891	181	5.2
4. Impr. grass	7	3	VL	27	55	1464	106	5.3
5. Impr. grass	14	6	VL	28	68	1678	134	5.4
6. Hairy indigo-grass	11	5	VL	27	109	1768	83	5.4
7. White clover-grass	15	5	VL	25	178	2649	178	5.5

[1]Average of 1959-1960 soil test results of 0-6″ depth.
[2]Very low.

The test values for the 4-year period with improved grass pastures were higher than those for the native condition by the following amounts: 133% in P_2O_5; 65% in K_2O; 105% CaO; and 40% in MgO. These increases reflect a sharp change in nutrient level in response to additions of these plant foods in the fertilizer treatment.

The CaO levels of the 7 and 14-year-old improved grass pastures were 164% and 188% above that of the 4-year improved grass treatment; these increases resulted from the greater period of time during which lime was applied to the pasture. Available P_2O_5 also was higher in the older improved pastures than in the more recently developed areas, testing 27 and 28 pounds per acre as compared to 21 pounds.

The K_2O level in the Hairy indigo-grass areas was 173% above the native treatment and the CaO level was 307% above.

The white clover grass treatment received the most intensive fertilizer practice in terms of average soil amendments per year, a fact clearly reflected by the high soil test levels of CaO, K_2O and P_2O_5 which were 510%, 345% and 178%, respectively, above those found in the native pasture. In general, the pH values increased above the native condition as the application of lime became heavier.

DISCUSSION

All nitrate values were low, this being the rule for flatwoods pastures of the type included in this study. Available P_2O_5 in pounds per acre increased sharply with the first increments of fertilizer. Additional applications did not cause a substantial increase. Determination of total soil phosphorus should permit a more thorough examination of this relationship.

Changes in K_2O levels over the native condition were moderate on grass, greater on Hairy indigo-grass and most pronounced on white-clover-grass pastures. Sampling date on the whiteclover-grass pastures, coming soon after fertilization probably contributed to the comparatively high K_2O soil test values. Available CaO figures were in close accord with the treatment record while those for MgO were more erratic. Differences in lime treatments are clearly indicated by the pH values shown in Table 2.

SUMMARY

Seven pasture treatment groups varying in rate of fertilization and years of improvement were studied with reference to their 1959 and 1960 soil tests of available nutrients. The tests on these pastures show many definite responses to variations in treatment. All nitrate values were low. Increase in available plant food supplies in pounds per acre were as follows: 9 to 28 pounds of P_2O_5; 40 to 178 pounds of K_2O; 434 to 2649 pounds of CaO and 129 to 181 pounds of MgO. The pH increased to a moderate degree as the rate of lime application became heavier.

Preliminary Investigations on the Mode of Action of Pangolagrass Roots in Reducing Cotton Root-Knot Nematode (Meloidogyne incognita acrita) Populations

JAMES A. WINCHESTER[1]

INTRODUCTION

The cotton root-knot nematode, (*Meloidogyne incognita acrita*, Chitwood, 1949) was not detected after pangolagrass, *Digitaria decumbens*, had grown for two months in infested soil (5, 6). Coastal Bermudagrass, Pensacola bahiagrass, carpetgrass, crabgrass and a species of sedge allowed the populations of the nematodes to build up to large numbers. These reports by Winchester and Hayslip also refer to field plot trials and observations on commercial farms which confirmed the results of the small plot experiments. A mixture of pangolagrass and nematode hosts such as Louisiana white clover, crabgrass, or sedge did not result in the elimination of the nematodes, and the degree of control was correlated with the purity of stand of pangolagrass. It was estimated that under normal field conditions two or more years in pangolagrass might be necessary in order to allow for the establishment of a "pure" stand of pangolagrass and elimination of the nematodes.

Since pangolagrass eliminated all evidence of root-knot namatodes in a relatively short period of time, it was suspected that more was involved than merely a non-host factor. McBeth (1), in 1945, reported variations in the resistance of several southern grasses to root-knot nematodes. The African marigold was found by Oostenbrink *et al.* (3) to be nematicidal when grown in soil infested by a root lesion nematode. Rohde and Jenkins (4), in 1958, reported that several nematode species were controlled when asparagus was planted in infested soil. Their work suggested that a nematicidal material responsible for this was a water soluble carbohydrate that diffused from the root into the soil.

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When this diffusate was applied to tomatoes growing in soil infested by the stubby-root nematode, the plants grew well and the nematodes were eliminated. Miller and Stoddard (2), studying the effect of disodium ethylenebisdithiocarbamate on rootknot nematode (*Meloidogyne* sp.) eggs, reported that aqueous solutions of the material decreased the number of eggs hatching, but when applied to the soil, this material increased the number of eggs that hatched.

MATERIALS AND METHODS

Virgin Immokalee fine sand, fertilized to produce optimum plant growth, was used in these tests. Treatments were arranged in randomized block designs with six replications. The crude extracts of pangolagrass were obtained by macerating 8 grams of various plant parts with 100 cc. of distilled water in a Waring blender. Cucumbers, seeded in 8-ounce paper cups, were used as indicator plants in order to determine population levels of the nematodes. About three weeks after the seeds germinated, the soil was washed from the cucumber roots, and they were rated from O-5 for no galling to severe galling, respestively. Root-knot inoculum was obtained by removing the galls and attached egg masses from the roots of tomato plants infested by the root-knot nematode (*M. incognita acrita*).

Hatching test: The root-knot galls and egg masses were placed in Syracuse watch glasses and randomly divided into three treatments of six replications each. The three materials used in this test (old root extract, young root extract, and distilled water) were applied to the chambers at the rate of 4 ml. per chamber.

Leachate test: Pangolagrass sod was planted in a series of nine one-gallon pots and sprigs of the grass planted in nine additional pots. These pots were equipped with a rubber stopper and glass tube in the drain hole. They were watered daily with excess water and the leachate was collected and applied to Louisiana S-1 white clover growing in root-knot infested soil. The clover seed were inocculated with the correct nitrifying bacterium immediately prior to planting. Soil samples were collected every two weeks from each pot of clover and seeded to cucumber indicator plants. Roots of these cucumber plants were rated three weeks later for root-knot galling.

PROCEDURE AND RESULTS

Pangolagrass extract test. A series of four tests were included in this study. In preliminary tests, the crude extracts of pangolagrass roots and a tap water check were applied daily to indicator plants seeded in root-knot infested soil. When rated three weeks later for galling, the plants which had received the root extract were free of galling while the check plants were moderately galled. In the second test, which was set up to test the results of the first, there were no differences between the root extract treatment and the water check. There was moderate galling on the cucumber indicator roots with both treatments.

In an effort to determine the cause of the inconsistent results in these two preliminary tests, the treatments listed in Table 1 were used in the third experiment.

TABLE 1.—THE EFFECTS OF EXTRACTS OF VARIOUS PARTS OF PANGOLAGRASS ON THE GALLING OF CUCUMBER ROOTS IN ROOT-KNOT INFESTED SOIL.

Treatment	Root-Knot Rating[1]
Old root extract	0.2
Young root extract	3.4
Leaf extract	2.4
Stem extract	2.8
Check	2.6
L.S.D. .05	0.6
L.S.D. .01	0.8

[1]Root-Knot Rating: 0 to 5; 0=No galling. 5=Severe galling.

Crude extracts of the leaves and stems of pangolagrass appeared to have no effect on the nematode population while the old root extract gave excellent control. Galling of the cucumber roots which had received the extracts of young pangolagrass roots was more severe than the check plants.

Three additional tests were completed to compare the extracts of young white pangolagrass roots, the old, brown ones and a water check. The results are listed in Table 2.

Note that in each of these tests there was significantly less galling on the cucumber plants which had received the crude extracts of the mature roots when compared to the other treatments.

Hatching. This study was conducted to observe effects of old and young pangolagrass root extracts and a water check on larval emergence from root-knot nematode eggs. Treatments were applied to the chambers containing galls and egg masses, and counts of emerged larvae were made two weeks later. Unhatched eggs were then removed to fresh solutions for two more weeks and counts of emerged larvae again made. The totals of the two counts were combined and are given in Table 3.

The extract from mature roots of pangolagrass apparently reduced the number of larvae emerging from eggs while the extract from young roots apparently increased the number emerging.

Pangolagrass root diffusate test. In order to determine if leachate from pangolagrass had any effect on root-knot nematodes in the soil, an

TABLE 2.—THE EFFECT OF EXTRACTS OF PANGOLAGRASS ROOTS ON THE GALLING OF CUCUMBER ROOTS IN ROOT-KNOT INFESTED SOIL.

Treatment	Test 1	Test 2	Test 3
Check	1.1[1]	2.3	2.5
Old root extract	0.5	0.0	0.1
Young root extract	1.5	3.2	3.3
L.S.D. .05	.6	.6	.8
L.S.D. .01	.9	.9	1.1

[1]Root-Knot Rating: 0 to 5; 0=No galling, 5=severe galling.

TABLE 3.—THE EFFECT OF PANGOLAGRASS ROOT EXTRACTS ON THE EMERGENCE OF ROOT-KNOT NEMATODES FROM EGG MASSES.

Treatment	Average number of nematodes emerged
Old pangolagrass root extracts	54
Young pangolagrass root extract	1510
Check, distilled water	724

additional study was conducted. Leachate from old pangolagrass was compared with that from young pangolagrass by applying these leachates and a water check daily to white clover growing in root-knot infested soil. The results are given in Table 4.

Root-knot was apparently eliminated in four weeks in pots receiving leachate from sod planted pangolagrass. Root-knot appeared to be more severe at that time in pots receiving leachate from sprig planted pangolagrass than in the water check. In six weeks root-knot had apparently been eliminated in pots receiving leachate from sprig planted grass. Root-knot was maintained at a moderate level throughout the test in the check pots.

DISCUSSION AND CONCLUSIONS

Apparent inconsistencies in the preliminary work with root extracts were thought to be due to the presence of a mixture of old and of young roots used for the extracts in the second test and of only old roots being used in the first test. Later tests, in which the old and young roots were separated, were made to determine if the age of the roots could be a factor in these inconsistencies.

The rate at which root-knot nematode populations were reduced with the application of old pangolagrass root extracts suggested the presence of a nematicidal material in the roots. More severe galling of indicator plants grown in the presence of extracts of young pangolagrass roots also suggested the presence of a hatching factor in the roots of the young grass. It should be emphasized that this work was done under greenhouse conditions and with *Meloidogyne incognita acrita* only.

The data obtained with the young pongolagrass root extracts confirmed the possibility of the presence of a hatching factor in these roots. To the author's knowledge, this is the first report of a hatching factor

TABLE 4.—THE EFFECT OF LEACHATES FROM PANGOLAGRASS, APPLIED TO CLOVER GROWING IN ROOT-KNOT INFESTED SOIL, ON THE POPULATION OF NEMATODES.

Treatments	Weeks After Treatments Were Started			
	2	4	6	8
Check	2.6[1]	0.3	2.3	2.6
Sod planted pangolagrass	0.6	0.0	0.0	0.0
Sprig planted pangolagrass	1.0	3.6	0.0	0.0

[1]Root-Knot Rating: O to 4; 0=No galling, 4=Severe galling.

for root-knot eggs being produced by any plant. The value of a hatching factor in a plant is readily apparent, particularly when associated with a non-host or with a plant producing a nematicidal material. The persistent stage of this nematode in the soil is the egg stage. If eggs are caused to hatch, the larvae are susceptible to unfavorable environmental conditions and to nematicidal materials in the soil; in addition, if no host is present, the larvae can live only a short time.

Evidence is given that the root-knot nematode, in the presence of a suitable host, may be eliminated in a short time by the application of the extracts of old pangolagrass roots. It was apparent from this study that leachate from the sprig planted grass had a different effect on the root-knot population than that from the sod planted grass. These differences did not exist after the sprigs had been growing about six weeks, suggesting that this grass was no longer producing the hatching factor and was then producing the nematicidal product.

The data indicate that pangolagrass may be a very effective factor in reducing root-knot nematodes in cultivated fields in a rotation program. This has been confirmed in small plots and in commercial fields.

SUMMARY

Studies to determine the mode of action of pangolagrass in reducing or eliminating the cotton root-knot nematode in Immokalee fine sand were conducted in greenhouse trials at the Indian River Field Laboratory, Ft. Pierce, Florida. Crude water extracts of mature pangolagrass roots prevented galling of cucumber roots growing in root-knot infested soil, while the extract of young pangolagrass apparently increased the galling as compared with a water check. In hatching tests, the extract of the mature roots was found to reduce larvae emergence while young root extract increased emergence as compared with a water check.

Leachate obtained by excessive watering of pots of pangolagrass sod and applied to white clover growing in root-knot infested soil apparently eliminated the nematodes in four weeks, while leachate from newly planted pangolagrass increased the nematode population at four weeks but eliminated them in six weeks. These conclusions are based upon the examinations for galling of indicator cucumber seedling roots planted in soil samples taken from the clover pots at two week intervals.

LITERATURE CITED

1. McBeth, C. W. Tests on the susceptibility and resistance of several southern grasses to the root-knot nematode, Heterodera marioni. Proc. Helminth. Soc. Wash. 12(2): 41-44. 1945.
2. Miller, P. M. and E. M. Stoddard. Increasing the hatching of eggs of cyst and root-knot nematodes with nabam. Science 128 (3336):1429-30. 1958.
3. Oostenbrink, M., K. Kuipert and J. J. s'Jacob. Tagetes als Feindpflanzen von *Pratylenchus arten.* Nematologica II (S):423s-433. 1957.
4. Rhode, R. A. and W. R. Jenkins. Basis for resistance of *Asparagus officinalis* var. *altilis* L. to the stubby root nematode *Trichodorus christiei* Allen 1957. U. of Md. Bul. A-97. 19pp. 1958.
5. Winchester, J. A. and N. C. Hayslip. Plant pangolagrass for root-knot control. Sunshine State Agr. Res. Rep. 5 (4):8-9. 1960.
6. ______ ______. The effect of land management practices on root-knot control. Fla. State Hort. Soc. Proc. (In Press). 1960.

Growth of Pineapple Orange Seedlings in Sand Cultures with Various Levels of K, Ca, and Mg

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Potassium (K), calcium (Ca) and magnesium (Mg) have been used in many ratios and amounts for citrus fertilization (1, 3, 4, 7). Many studies of the effects of K, Ca and Mg on citrus tree growth have been done in the field or under conditions where the entire plant could not be harvested. Other studies have been conducted in sand cultures with main emphasis on fruit quality associated with various levels and ratios of cations (1, 4, 6, 8, 9).

Past studies seem to indicate that K exerts its greatest influence on fruit quality (3, 6), Ca influences overall growth of the tree (7) and Mg shows no effect on tree growth except when deficiency symptoms are evident (4).

Pineapple orange seedlings were grown for 18 months under 37 treatments in outdoor sand cultures to determine what effect wide ranges and ratios from very deficient to excessive levels of all 3 cations have on growth, moisture content of leaves and stems, and level of each cation at which the most efficient absorption takes place and how this is related to growth.

METHODS AND MATERIALS

The culture vessels consisted of 108 sections of 8-inch vitreous clay tile 3 feet long sunk in the soil. A cement bottom with a 1-inch hole in the center was placed in each tile which was then filled with 100 lbs. of fine, white quartz sand. Capillary contact between the sand and the sandy subsoil provided positive drainage so that there was no liquid accumulation in the vessels and excellent root growth was possible throughout the column. Three young Pineapple orange seedlings were set in each tile. Three replicates were used for each treatment except 35 to 37 in which only 2 replicates were used.

The triangle method (2) was used to vary the levels of K, Ca and Mg. The total cation equivalence was the same in all solutions. The 3 cations were supplied as nitrates so that the only varying ions in the nutrient solutions were K, Ca and Mg as carriers of the nitrate. Figure 1 illustrates the triangle and the treatments used. The K, Ca and Mg levels ranged from 2 to 96% of the total bases. The complete nutrient solutions contained 12 me/1 total bases and a ratio of 80:20 of NO_3 nitrogen to NH_4 nitrogen. This strength of solution was chosen because in earlier studies (6, 9) it gave good growth with a total base accumulation of about 200 me /100 g. dry leaf tissues with a wide range of base reciprocation evident.

One liter of the respective nutrient solutions was added once a week and water twice a week in amounts that induced leaching. At harvest

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height, fresh and dry weight; moisture content; K, Ca and Mg levels of leaves, shoots and roots; total uptake of K, Ca and Mg; and efficiency of absorption were measured.

RESULTS AND DISCUSSION

Plant Growth

The treatments in Table 1 are arranged in order of increased total growth. The best growth occurred when the K:Ca:Mg ratios were near the center of the nutrient triangle. The three best treatments were 33:33:33, 42:42:16 and 16:42:42 ratios of K:Ca:Mg. When the Ca per-

TABLE 1.— RELATION OF K, CA, AND MG TO MEAN LEAF NUMBER, MEAN DRY WEIGHTS OF LEAVES, SHOOTS, AND ROOTS PER POT OF PINEAPPLE ORANGE SEEDLINGS, AND THE PROPORTION OF TOTAL GROWTH IN THE PLANT PARTS.

Treat. No.	Sol. ratio K:Ca:Mg	No. Leaves	Dry weight (grams) Leaves	Shoots	Roots	Total	Percent total dry weight as Leaves	Shoots	Roots
37	96: 2: 2	29	7	16	31	54	13	30	57
1	2: 2: 96	81	17	20	44	81	21	25	54
36	92: 4: 4	67	18	30	61	118	15	33	52
5	2:96: 2	135	28	42	84	153	18	27	55
6	4: 4: 92	127	31	44	82	157	20	28	52
19	24: 2: 74	137	36	64	85	184	20	34	46
2	2:24: 74	155	36	53	96	185	19	29	52
31	71: 8: 21	120	34	64	110	208	16	31	53
33	74: 2: 24	116	37	79	99	215	17	37	46
28	49: 2: 49	126	38	66	116	220	17	30	53
4	2:74: 24	157	44	66	111	221	20	30	50
9	8: 8: 84	168	43	74	110	227	19	33	48
3	2:49: 49	170	46	70	122	238	19	30	51
35	84: 8: 8	107	40	85	139	240	17	25	58
10	8:21: 71	179	47	77	121	244	19	32	49
34	74:24: 2	93	34	97	123	255	13	39	48
29	49:49: 2	150	44	102	111	258	17	40	43
17	21: 8: 71	187	47	84	129	260	18	32	50
20	24:74: 2	159	50	106	135	290	17	36	47
30	68:16: 16	174	49	82	150	291	17	31	52
8	4:92: 4	185	59	96	134	315	19	38	43
22	42:16: 42	183	64	88	176	333	19	28	53
14	16:16: 68	207	61	123	159	343	18	36	46
26	48: 4: 48	182	63	121	198	382	16	32	52
32	71:21: 8	258	65	150	175	390	17	38	45
13	8:84: 8	164	80	147	167	393	20	38	42
12	8:71: 21	205	74	148	173	395	19	37	44
27	48:48: 4	201	64	139	202	404	16	36	50
7	4:48: 48	267	80	140	181	405	20	35	45
11	8:46: 46	240	75	152	181	408	18	38	44
24	46: 8: 46	221	66	141	208	415	16	34	50
18	21:71: 8	233	74	151	199	424	17	36	47
25	46:46: 8	214	76	166	192	433	18	38	44
16	16:68: 16	239	83	154	200	436	19	35	46
15	16:42: 42	257	78	171	221	470	17	36	47
21	33:33: 33	266	89	180	222	490	18	37	45
23	42:42: 16	224	87	195	221	502	17	39	44
L.S.D.	.05		25	54	64	46			
	.01		33	72	85	61			

centage was exceeded by either or both of the other two cations, growth was depressed. Thus, a 42:16:42 ratio was not nearly as good a combination as the three above. The range in total weight was 54 g. per 3 seedlings which received a 96:2:2 ratio to 502 g. when the nutrient solution ratio was 42:42:16 of K:Ca:Mg. The important requirement seems to be that either Ca be the dominant or co-dominant cation and that no single cation makes up more than 50% of the total cations. The Mg level should be more than 8% of the total cations but not more than K or Ca. Also, while the number of combinations used limits the possible comparison, it is evident that when the proportion of any one base was low, the plant grew better if the two other bases were equally divided.

Weight of the plant parts and number of leaves, in general, followed the same alignment as total growth. Leaf number showed less relation to total growth than other physical measurements. This is no doubt attributable to the modifying effect of leaf size and, to some extent, differential defoliation.

The mean leaf weight increased as K in the solution increased (Table 2). The correlation coefficient showing the relation between solution K and mean leaf weight is equal to +0.55. Mean leaf weight is not correlated with leaf K, Ca or Mg (Table 2). The reason for no correlation is no doubt because of the extreme levels of the cations in the leaf tissue.

The lack of correlation may be attributable to the extreme levels of cations used. Thus, low levels of Mg induced continual defoliation so

TABLE 2.—MEAN LEAF WEIGHT AND LEAF MOISTURE CONTENT IN RELATION TO RATIO OF BASE ELEMENTS IN NUTRIENT SOLUTION.

Treat. No.	Sol. ratio K:Ca: Mg	Dry wt. Mg/leaf	Leaf Moisture %	Treat. No.	Sol. ratio K:Ca: Mg	Dry wt. Mg/leaf	Leaf moisture %
1	2: 2: 96	71	67	20	24:74: 2	103	68
2	2:24: 74	77	62	21	33:33: 33	111	68
3	2:49: 49	90	65	22	42:16: 42	121	69
4	2:74: 24	94	62	23	42:42: 16	130	68
5	2:96: 2	69	66	24	46: 8: 46	102	68
6	4: 4: 92	81	68	25	46:46: 8	117	70
7	4:48: 48	100	65	26	48: 4: 48	115	68
8	4:92: 4	112	62	27	48:48: 4	111	69
9	8: 8: 84	85	68	28	49: 2: 49	100	69
10	8:21: 71	88	67	29	49:49: 2	100	71
11	8:46: 46	108	66	30	68:16: 16	94	71
12	8:71: 21	120	66	31	71: 8: 21	94	71
13	8:84: 8	100	65	32	71:21: 8	131	71
14	16:16: 68	101	67	33	74: 2: 24	114	72
15	16:42: 42	101	67	34	74:24: 2	122	73
16	16:68: 16	116	65	35	84: 8: 8	124	71
17	21: 8: 71	84	69	36	92: 4: 4	89	73
18	21:71: 8	112	67	37	96: 2: 2	81	76
19	24: 2: 74	87	71				

Correlation coefficients between:

Solution K and leaf moisture = +.73
Solution Ca and leaf moisture = −.64
Solution Mg and leaf moisture = −.29
Solution K and leaf weight = +.55
r required for significance at 99:1=0.42

Leaf K and leaf moisture = +.09
Leaf Ca and leaf moisture = −.08
Leaf Mg and leaf moisture = .03
Leaf K and leaf weight = +.03

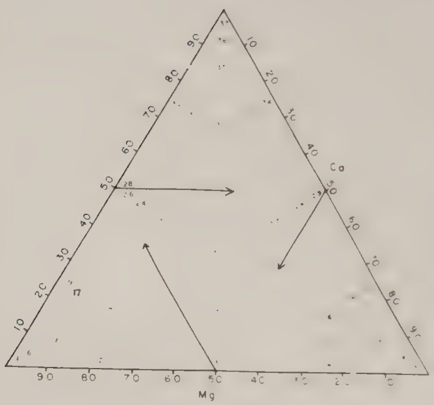

Fig. 1.—Treatment triangle showing the 37 different ratios of K, Ca and Mg used in nutrient solutions. Arrows show direction of constant percentage in each element. For example, treatment 1 consisted of 2% K, 2% Ca and 96% Mg while treatment 21 contained equal meq of all 3 bases.

that plants deficient in this element carried fewer but larger than average sized leaves irrespective of K level. Even so it is not apparent why solution K showed a positive correlation to leaf size while leaf K did not.

Figure 2A, a general view of some of the seedlings arranged in a triangular pattern similar to the treatment triangle, shows the increased growth of the shoots toward the center of the triangle where the treatments had better balanced levels of K, Ca and Mg.

Figures 2 B, C and D illustrate that Mg was not as limiting to seedling shoot growth as K and Ca. The seedlings in Figure 2 B, where Mg made up 2% of the cations in the nutrient solutions, were larger on the average than when K or Ca was supplied at the 2% level (Figures 2 C and D, respectively).

The ratio of leaf weight to total plant weight was practically constant regardless of treatment or plant size suggesting the obvious dependence of plant size on leaf quantity (Table 1). The better treatments produced plants with slightly less than 50% root weight while the poorer treatments produced plants with more than 50% root weight (Table 1). Figure 3 A illustrates the good root system of 3 seedlings which received a balanced nutrient solution containing a ratio of 42:42:16 of K:Ca:Mg. The dry weight of these root systems was 221 g. versus 31 g. for the roots in Figure 3 B from seedlings which received an unbalanced nutrient solution with a ratio of 96:2:2 of K:Ca:Mg.

Considering the 3 treatments that give significantly better growth than all others, it is evident that Ca varies within narrow limits while K and Mg vary rather widely. The range of 16-42% of cations for K and Mg and 33-42 for Ca encompasses a range of 75-200 ppm K, 23-61 ppm Mg and 80-100ppm Ca. Presumably, any nutrient solution within these boundaries would be a good culture solution for orange seedlings if the other elements were adequately supplied.

MOISTURE CONTENT OF TISSUES

The mean leaf weights and moisture content of the leaves in relation to ratio of cations in the nutrient solutions are given in Table 2. Although the range was not great, the effect was so consistent that the correlation

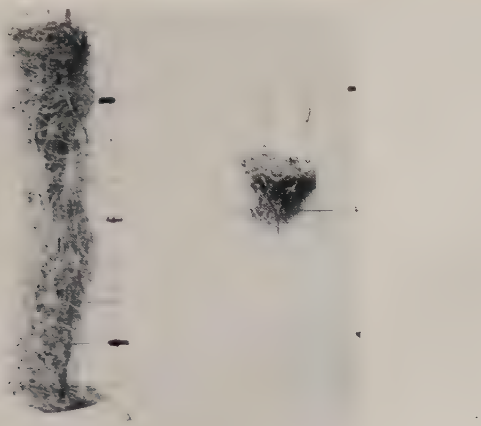

Fig. 3.—(A) (left). Root system from 42:42:16 ratio of K:Ca:Mg treatment.
(B) (right). Root system from 96:2:2 ratio of K:Ca:Mg treatment.

Fig. 2.—(A) (upper left) General view showing increased growth toward center of triangle.
(B) (upper right) L to R—2:96:2, 24:74:2, 49:49:2, 74:24:2 and 96:2:2.
(C) (lower left) L to R—2:2:96, 2:24:74, 2:49:49, 2:74:24 and 2:96:2.
(D) (lower right) L to R—96:2:2, 74:2:24, 49:2:49, 24:2:74 and 2:2:96.

coefficient between K in the solution and moisture content equaled + 0.73. High moisture content of citrus foliage has been associated with high K before (5, 8), but none of the citrus had been grown in such a wide range of K treatments as in the present study.

The strong negative correlation with Ca and the weak negative correlation with Mg reflects strong reciprocation of K and Ca in absorption and weak reciprocation between the absorption of K and Mg. Since K absorption depresses the absorption of both of these cations, although unequally, it follows that they would show an opposite association to K in effect on moisture content.

Apparently anomalous leaf moisture in plants of treatment one may be attributed to a high proportion of young leaves, although this was not determined.

The moisture content of the stems also increased as K was increased

TABLE 3.—MEAN PERCENTAGE AND MILLEQUIVALENTS OF K, CA, AND MG IN THE DRY LEAF TISSUE IN RELATION TO RATIO OF BASE ELEMENTS IN NUTRIENT SOLUTION.

Treat. No.	Sol. ratio K:Ca:Mg	Percentage in dry leaves K	Ca	Mg	Me. per 100 g. dry leaves K	Ca	Mg	Total
37	96: 2: 2	4.65	0.57	0.08	119	28	7	154
1	2: 2: 96	0.34	1.29	1.38	9	65	113	187
36	92: 4: 4	4.40	0.66	0.11	113	33	9	155
5	2:96: 2	0.42	4.14	0.12	11	207	10	227
6	4: 4: 92	0.48	1.54	1.14	12	77	94	183
19	24: 2: 74	1.76	1.20	0.77	44	60	63	167
2	2:24: 74	0.30	2.23	0.93	8	112	77	197
31	71: 8: 21	3.29	0.68	0.28	84	34	23	141
33	74: 2: 24	3.33	0.70	0.32	85	35	26	146
28	49: 2: 49	2.75	0.84	0.57	70	42	47	159
4	2:74: 24	0.27	4.21	0.42	7	211	35	253
9	8: 8: 84	0.65	1.55	0.91	17	78	75	170
3	2:49: 49	0.27	3.18	0.61	7	159	50	216
35	84: 8: 8	3.72	0.87	0.13	95	43	11	149
10	8:21: 71	0.79	1.72	0.69	20	86	57	163
34	74:24: 2	3.45	1.09	0.12	88	55	10	153
29	49:49: 2	3.03	1.61	0.90	78	80	7	165
17	21: 8: 71	1.53	1.29	0.68	39	65	56	160
20	24:74: 2	2.19	2.29	0.10	56	115	8	179
30	68:16: 16	3.12	1.12	0.21	80	56	17	153
8	4:92: 4	0.48	4.30	0.15	12	215	12	239
22	42:16: 42	2.48	1.36	0.44	64	68	36	168
14	16:16: 68	1.31	1.49	0.62	34	75	51	160
26	48: 4: 48	2.52	0.98	0.55	64	49	45	158
32	71:21: 8	3.07	1.45	0.15	78	72	12	162
13	8:84: 8	0.40	3.05	0.19	18	168	16	202
12	8:71: 21	0.60	3.28	0.29	15	164	24	203
27	48:48: 4	2.90	1.72	0.11	74	86	9	169
7	4:48: 48	0.40	3.05	0.52	10	153	43	206
11	8:46: 46	0.59	2.78	0.48	15	139	40	194
24	46: 8: 46	2.37	1.18	0.47	61	59	39	159
18	21:71: 8	1.54	2.62	0.15	40	131	12	183
25	46:46: 8	2.67	1.91	0.16	68	95	13	176
16	16:68: 16	0.98	2.89	0.23	25	145	19	189
15	16:42: 42	1.09	2.09	0.41	28	105	34	167
21	33:33: 33	2.06	1.97	0.34	53	99	28	180
23	42:42: 16	2.65	2.02	0.21	68	101	17	186
L.S.D.	.01	0.10	0.41	0.08				

in the nutrient solution. The range of moisture content of the stems was 46 to 53% of the fresh weight. The correlation coefficient showing the relation between K and shoot moisture was significant at odds of 99:1

BASE COMPOSITION OF LEAVES

Table 3 presents data showing the relation of K, Ca and Mg uptake in relation to their ratios in the nutrient solutions. The treatments are arranged in the order of plant size, as Table 1.

The percentage of K, Ca and Mg in the dry leaf tissue varied over a wide range as expected. Poor growth resulted when 2 of the cations were deficient in the leaf tissue. Better growth occurred when only one cation was deficient and best growth when none of the 3 cations was deficient as shown by the last three treatments in Table 3. It is rather generally agreed that K below 0.5, Ca below 1.5 and Mg below 0.15% of the dry leaf weight are deficient levels. The cation levels of the best 6 treatments fell above these limits.

The balance of elements in the plant apparently is more important than total me absorbed since no consistent relation between me and growth was found. Citrus grown in sand cultures supplied with a nutrient solution containing 12 me/l of these 3 bases will accumulate approximately 200 me/100 g. dry mature leaf tissues (6, 9). In the present study approximately 180-200 me/100 g. dry leaf tissue was found except when Ca was exceedingly high or when K was exceedingly high. A number of treatments produced relatively low total me, indicating that base substitution is not complete over wide extremes.

The overall mean efficiency of absorption based on the amount of K, Ca and Mg present in the seedlings at the end of the test was 28, 44 and 25 percent, respectively, of that applied. Best growth resulted in the treatments where the absorption efficiency was near the overall average.

Absorption is a selective process not conditioned by mass action alone. This is illustrated in Table 4 in which data from selected treatments are presented to show that when K in the solution is gradually replaced by equal me of Ca and Mg, more Ca than Mg was absorbed in reciprocation for K. Such can easily explain the relative strengths of the correlations of these two elements as they oppose K (Table 2).

SUMMARY

Pineapple orange seedlings were grown for 18 months in outdoor sand cultures imbedded in the soil. A triangle method was used to vary the levels of K, Ca and Mg in 37 treatments. The nutrient solutions contained 12 me of bases/l. with the range of each cation being 2 to 96% of the total. All other ions were at a constant level. Growth, moisture content, and K, Ca and Mg composition were measured at harvest.

Dry weight measurements indicate that good growth of roots, stems, and leaves occurred when the nutrient solutions were made from the middle of the treatment triangle. When any of the cations deviated very much from the center, poorer growth resulted. Relatively good growth occurred, however, over a wide range of any given element provided the other 2 were supplied in equal amounts. Of the 3 cations involved, Mg had the least influence on growth.

TABLE 4.—SELECTED TREATMENTS ILLUSTRATING THE PREFERENTIAL ABSORPTION OF CA OVER MG IN THE REPLACEMENT OF K.

Treat. No.	Sol. ratio K:Ca:Mg	Me. per 100 g. dry leaves K	Ca	Mg	Total
37	96: 2: 2	119	28	7	154
36	92: 4: 4	113	33	9	155
35	84: 8: 8	95	43	11	149
30	68:16: 16	80	56	17	153
21	33:33: 33	53	99	28	180
15	16:42: 42	28	105	34	167
11	8:46: 46	15	139	40	194
7	4:48: 48	10	153	43	206

Leaf analyses showed a wide range of K, Ca and Mg levels; however, the best treatments contained levels of the 3 cations above the deficiency level of each.

Roots made up slightly less than 50% of the total dry weight in the better treatments and more than 50% in the poor treatments.

Moisture content of leaves and stems increased as the K level of the nutrient solution increased. Ca, the major reciprocating element for K, showed a negative correlation between solution concentration and moisture content of leaves. Tissue concentrations of the 3 base elements showed no correlations to moisture content of tissue or to leaf size.

The best growth occurred when the efficiency of absorption was near the overall average absorption efficiency which was 28, 44 and 25% of the K, Ca and Mg applied.

LITERATURE CITED

1. Chapman, H. D. and S. M. Brown. Potash relation to citrus nutrition. Soil Sci. 55: 87-100. 1943.
2. Miller, E. C. Plant Physiology. Ch. 5, McGraw-Hill Book Co., N. Y. 1938.
3. Reuther, Walter, T. W. Embleton and W. W. Jones. Mineral nutrition of tree crops. Ann. Rev. of Plt. Physiol. 9: 175-206. 1958.
4. Reuther, W. and P. F. Smith. Relation of nitrogen, potassium, and magnesium fertilization to some fruit qualities of Valencia orange. Proc. Amer. Soc. Hort. Sci. 59: 1-12. 1952.
5. Smith, P. F. and G. K. Rasmussen. Relation of fertilization to winter injury of citrus trees. Proc. Fla. State Hort. Soc. 71: 170-175. 1958.
6. Smith, P. F. and G. K. Rasmussen. Relation of potassium nutrition to size and quality of Valencia oranges. Proc. Amer. Soc. Hort. Sci. 74: 261-265. 1959.
7. Smith, P. F. and W. Reuther. Fruit Nutrition, ch. 6. (Somerset Press, Somerville, N. J.) 907 pp. 1954.
8. Smith, P. F., W. Reuther and G. K. Scudder. Effect of differential supplies of nitrogen, potassium, and magnesium on growth and fruiting of young Valencia orange trees in sand cultures. Proc. Amer. Soc. Hort. Sci. 61: 38-48. 1953.
9. Smith, Paul F., Walter Reuther, A. W. Specht and Gustave Hrnciar. Effect of differential nitrogen, potassium, and magnesium supply to young Valencia orange trees in sand culture on mineral composition especially of leaves and fibrous roots. Plt. Physiol. 29: 349-355. 1954.

THE CENTRAL AND SOUTHERN FLORIDA FLOOD CONTROL DISTRICT AFTER 10 YEARS OF PROGRESS

Introductory Remarks

G. E. DAIL, JR.*

During the more than twenty years of investigation and evaluation of Florida soil, crop and related matters, your Society has frequently turned its attention to water relationships. This has been especially true with reference to conditions in central and southern Florida. Your meetings have provided a forum where local problems and conditions have been appraised and discussed and from which have come increased awareness of the aims and purposes of the existing Project.

It was in Clewiston in 1948 that the overall water control program, then under contemplation for south Florida, was the subject of a Society symposium. Some of you may recall that Harold Scott discussed the plans for the present Project; however, his heart was not in it because young Malbee Russell was being born in Jacksonville at the time.

The significance of water conservation also was given recognition at the 1951 meeting when Turner Wallis led a panel discussion on that topic. This and the earlier meeting referred to above followed the two really basis meetings in 1942 and 1943, both of which dealt exclusively with the physical and financial problems of the original Everglades Drainage District and laid much groundwork for the future, especially thru the presence and active participation in both meetings of Commissioner of Agriculture, Honorable Nathan Mayo.

Later, right here in Clearwater, Dr. R. V. Allison, in 1956 brought you the benefit of the Everglades Experiment Station's long time research into the influence of drainage and cultivation on subsidence under peat soil conditions. In addition, that same meeting included a symposium on water resources and utilization, having State-wide implications.

We at the Central and Southern Florida Flood Control District very much value your invitation to report on our progress during the past ten years. Your Society has devoted one-fourth of its program to the District. The agenda, which you have, reveals that the physical, economic and administrative aspects of the District will be taken up in that order.

Appropriately, W. Turner Wallis will open the program and discuss the early development and present status of the Project.

*Executive Director, Central and Southern Florida Flood Control District, 901 Evernia Street, W. Palm Beach.

The District's Heritage from the Past as a Guide to its Future Direction

W. TURNER WALLIS[1]

To those who are aware of the precariously thin line existing between a condition of prosperity for southern Florida and the disasters possible at any time from extremes of flood and drought, the Central and Southern Flood Control Project stands out as the single hope for the future. It is just that important.

Today, the water control needs of peninsula Florida are generally understood; engineering methods and administrative arrangements for meeting these needs are within reach; requirements for public co-operation and financial help are viewed sympathetically. The one instrument presently capable of welding these into an effective water control program for the area is the Central and Southern Florida Project. Ample proof of this exists in the notable success already achieved in the reduction of flood damages in localities where works of the project are installed and functioning. There is every indication that here is a multi-purpose undertaking fully in step with the growth and development character of the large area it is designed to serve.

But such a project could not have been conceived in thin air and brought into being overnight. It is no one man's accomplishment, nor does credit for its eminent success belong exclusively to those who have administered it. It is the product of experience accumulated over more than a century; of prior successes and failures; of arduous labors performed by bold men of succeeding generations, who saw first the desirability and then the absolute necessity of bringing water control to this promising land. This is the heritage in which the existing project is founded and by which its direction is shaped. It is therefore helpfully instructive to recall this heritage by reviewing the significant developments of the past.

Central and Southern Florida is not naturally suited for intensive human habitation and use. By nature it is an area of vast marshes and swamps, with its flat expanses rising slightly above the level of surround-

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[1]Consulting Engineer, W. Turner Wallis and Associates, Center Building, Tallahassee.

Mr. W. Turner Wallis was born in Clarksburg, West Virginia, in 1900. He was educated at Virginia Military Institute where he received his Bachelor of Science degree in Civil Engineering in 1920.

After graduation, and until 1925, Mr. Wallis served as instrument man to the Assistant Chief Engineer for the Everglades Drainage District. He was engaged from 1925 to 1949 in private practice as professional engineer, land surveyor, real estate broker and appraiser, specializing in the planning and administration of government services. From 1949 to 1956 he was Executive Director and Chief Engineer for the Central and Southern Florida Flood Control District. He has served as Engineer for the State Land Use and Control Commission and Engineer for the Trustees of the Internal Improvement Fund. Mr. Wallis is a registered engineer, land surveyor and real estate broker. He is a member of the American Society of Civil Engineers, National Society of Professional Engineers and the Florida Engineering Society.

ing seas—in effect, one great flood plain for the 50-60 inches of annual rainfall. So formidable was the area that, although it was one of the first known to Western man, it was one of the last to be settled. In spite of various inducements, it was almost 400 years after discover of the peninsula before appreciable settlement got underway. As late as 1900 there were no more than 20,000 people in the area. By 1910, however, this figure had doubled, and between 1910 and 1920, population tripled. What happened to at last stimulate a southerly movement of population and change that part of the state from a land of wonder and speculation to one of problematical reality? The answer to this question has its beginnings still farther back in time.

Although the Florida peninsula has been subject to periodic inundation and drought practically since it emerged from the sea, these phenomena did not become problems until they began to retard man in his desire to occupy and use the area. Except by the Indian aborigines, this desire was not really manifested until the 1840's, when a few explorers, Indian-fighters and visionaries started speculating on the agricultural potential of these semi-tropical lands. Speculation was one thing, however, and action another. The problem of reclamation—formidable enough in these days of modern machinery and co-operative financing—was overwhelming at that time.

Recognition of just such problems faced by frontier states prompted the federal government in 1850 to pass an act conveying sub-marginal lands in the Public Domain to the various affected states, subject to the condition that the lands be used in a manner to secure their own reclamation. Florida subsequently acquired large tracts of lowlands under this act, and a program of reclamation might have gotten an important start at that time but for the over-shadowing emphasis placed on the usefulness of these lands as inducements for railroad construction. In consequence, the intention of the federal government—which was prevented by current law from entering directly into internal improvement programs in the states—was temporarily thwarted. Many years later, however, the state found itself so desperately involved in financial complications as a result of its railroad ventures that it finally began promoting reclamation possibilities in south Florida in hopes of selling its swampland holding in that area. This turn of events opened the door for more important things to come.

With lands purchased from the state, or under arrangements whereby lands were offered as premiums for reclamation work, a great deal of privately financed activity was undertaken in the closing years of the 19th Century. While these private efforts actually produced very little in the way of drainage and water control, they were instrumental in stimulating the greatest interest yet in the development prospects of lower Florida. Many of the lands were re-sold to other private parties, and a variety of agricultural enterprises were established. In the final analysis, it was this stimulus, combined with the contemporary construction of the Plant and Flager railroads down the long axis of the state, that opened the area to eventual settlement and development.

But while private enterprise had sparked the interest in south Florida reclamation, it could not, in view of the magnitude of the task and the unsure economic return, hope to accomplish this end single-handedly. By this time it had become apparent in many parts of the Nation that

water control measures should be undertaken initially on a scale far too grand for successful accomplishment by private interests. State and special local authorities had begun to fill this need in other areas such as the lower Mississippi Valley and the Miami River Valley of Ohio, and even the federal government had begun to broaden its interest to include limited responsibilities in the field of reclamation and flood control. The survey of lower Florida by the U. S. Army Corps of Engineers, authorized by the Rivers and Harbors Act of 1899, was ostensibility in pursuance of the federal government's responsibility for navigational improvement; but behind the scenes, attitudes were already forming which would lay the groundwork for a more significant involvement 30 years later in bringing flood control to that same area.

If private enterprise was incapable of providing for lower Florida's major reclamation needs, who was to do the job? In 1903, the state acquired, by patent from the United States, title to the last remaining large tract of swamp and overflowed lands in Florida—over 2,862,000 acres south of Lake Okeechobee. This patent included most of the Everglades proper, an area which because of the potentially great productivity of its organic soils, had been attracting attention from the reclamationists for many years. Thus, the situation as the 20th Century began was made to order for direct involvement by the state in a major reclamation enterprise.

Events during the next quarter-century provided an especially valuable part of the experience which made today's success possible. By laws in 1905, 1907, and 1913, the state-administered project, finally known as the Everglades Drainage District, was launched. Because of the questionable aspects of its engineering plan, its legal difficulties and financial complications, and its ultimate failure as an administrative entity, the true value of this great pioneer effort is often not fully appreciated. Yet, by the trials it faced in devising workable laws, engineering plans and methods, financial means, tax procedures, and in many other fields, the Everglades Drainage District made an invaluable contribution to ultimate success.

Of more immediate importance, however, this District was responsible for opening up the agricultural potential of the fertile mucklands in the vicinity of Lake Okeechobee. Its mission was drainage, and drain it did. Between 1906 and 1927, more than 600 miles of canals were dug for the rapid removal of unwanted water. The level of Lake Okeebochee, and, consequently, the surrounding mucklands, was lowered as much as six feet below its natural high stages. Response to this economic stimulus was immediate, and various agricultural enterprises developed quickly along the southern and eastern shores of the lake. This unique area remains today one of the foremost producers of truck and specialty crops in the nation.

Up until this time, man's concern in southern Florida had been primarily with reclamation. Indeed, this had genuinely been his greatest need. Concurrent with the major efforts toward this end, however, the population shift to the South began in earnest. A developing agricultural economy accounted for part of this, while the rest was attributable largely to the incipient resort complex stimulated by discovery of Florida's delightful climate. Such encroachment onto formerly virgin terrain inevitably resulted in a multitude of new problems of dealing with water. Hurri-

canes and heavy rainfall especially were severely felt by the early settlements of the area. In addition to draining surplus water for land reclamation, man now had to protect himself and his developed properties against the sudden return of too much water. Enter a new phase of water resources management in southern Florida: flood control.

The the time of the flood disasters of 1926 and 1928, the federal government still had not become involved extensively in improvement proprams for the lower Florida peninsula. Its interest had been confined largerly to a number of harbor and inconsequential navigation projects. The loss of almost 3,000 lives to catastrophic flooding had a telling effect in Congress, however, and despite the fact that general authority for flood control work was not to come until 1936, the Corps of Engineers was authorized in 1930 to undertake the containment and control of Lake Okeechobee as a rivers and harbors project. Anticipating passage of this act, the Florida Legislature in 1929 created the Okeechobee Flood Control District to co-operate with the federal authorities. Together, they were responsible for the construction of the levees, hurricane gates and channel improvements which have served so well to this day in reducing damage from overflow of Lake Okeechobee.

In the events so far, it is easy to recognize a pattern involving response to need. These needs—reclamation, navigation, flood protection—were first felt one at a time, and in the same order their solution was sought. Development of southern Florida was not too long underway, before the variety and incidence of these needs had increased manyfold, and had become inseparably interrelated, one among the others. Droughts—paradoxically common in this land of abundant rainfall—created problems of irrigation supply in agricultural areas and aggravated the inland advance of salt water along the coast. Excessive drainage proved detrimental to the organic soils of the glades, and wrought such drastic changes in the natural habitat conditions that many species of fauna and flora were threatened with extinction. Too much water—in addition to damaging improved property, restricting use of the land and in extreme cases jeopardizing human life—disrupted sanitary measures and brought on problems of widespread pollution: Popular attitudes concerning the proper or most urgent ends to be served in water resources management turned in one direction and then in another, depending primarily on whether conditions were currently wet or dry. Finally came a realization that was thereafter to have an all-important effect on policy in the area; that although water was indeed the basis for many of south Florida's most magnitudinous problems, it was at the same time one of the most valuable assets; that the prosperity of this growing area depended on a new approach to water resources management that could reflect to its proper degree and in its correct relationship all of the needs of this area.

Such a realization, born of a hundred years' experience, shaped the concept of the Central and Southern Florida Flood Control Project. By 1947, when a hurricane disaster of exceptional proportions occurred, it was apparent to all concerned that a new project was necessary and that it must be undertaken on a truly comprehensive basis for that entire part of the peninsula in any way hydrologically related. The result, of course, was the design of the current multi-purpose plan. Official federal and state endorsement was provided by act of Congress in 1948, authorizing the project, and by act of the Florida Legislature in 1949, creating

the Central and Southern Florida Flood Control District. Assurances of a genuinely co-operative and fully supported project were provided by involving local interests on a partnership basis. The almost amazing speed with which this gigantic project was expedited through planning and authorization stages attests the recognition of its need and the popularity of its purpose.

For the architects of the Central and Southern Florida Flood Control Project, time had proved the necessity for a multipurpose approach. This approach has been taken. To be sure, actual construction progress has been slow on many segments of the plan—slower even than anticipated—but still it is possible to point with satisfaction to the work already completed. So far, some $68,000,000 in public funds have been expended for key facilities which are already proving their worth. Yet, so vast is this overall undertaking that this progress over eleven years represents no more than 20% toward completion. Obviously this pace must be stepped up.

More than quickening its construction pace, however, this phoject must stay abreast of the changing needs it must serve in this land of rapid growth and development. A rush to an early completion of the present plan of improvement will have accomplished little if by that time it is not in keeping with the needs of the day. Above all, the project must be sensitive to these changing requirements and readily adaptable to provide for them. In these two major respects, this project can hold the promise of success where previous efforts, more limited in scope and purpose, have failed. This guidance is the project's heritage from the past. If it is heeded, the Central and Southern Florida Flood Control Project may in fact be the culmination of a century-long effort. If not, it will become just another addition to a growing experience that may someday produce a successful water control program for this part of the state.

Hydrologic and Hydraulic Problems as Related to the Design of Project Works

EDWIN W. EDEN, JR.[1]

The hydrologic and hydraulic problems involved in planning and design of the Central and Southern Florida Flood Control Project are varied, covering many fields. Some are unique requiring specialized data in addition to the basic data required for the design of the usual type of major drainage and flood control project.

A large portion of this project is located in the coastal region. In some areas, it is surrounded by water on three sides. The interior region is a vast area of low elevation and relief known as the Everglades. This area is very poorly drained under natural conditions. Lake Okeechobee, at the northerly end of the Everglades, is the second largest body of fresh water in the United States. The lake has peculiar hydrologic problems arising from wind action, which are aggravated by its extremely shallow depth. The northerly portion of the 15,000 square miles encompassed by the project includes the drainage basins of the Kissimmee and upper St. Johns Rivers. While the drainage courses of these rivers lie through a series of lakes and marshes, the uplands are relatively high for this region, and there is sufficient slope to afford normal drainage.

The hydrologic and hydraulic problems fall into several different facets. First, those associated with estimating the volume of excess water—primarily rainfall, evapotranspiration, and other losses— and the distribution in time of the runoff resulting therefrom; second, the problems associated with the effect of wind on water levels on Lake Okeechobee and other lakes—including conservation areas—and on the tides in coastal areas; third, the determination of the vegetative resistance to the movement of water in marshlands when acted upon by gravity and/or wind;

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Mr. Eden was born in Highland Park, New Jersey, in 1911. He received his Bachelor of Science degree in Civil Engineering from Rutgers University in 1933 and his Master of Science degree in Hydraulics from the University of Iowa in 1938.

Mr. Eden was Project Engineer for the Soil Conservation Service in New Jersey and Vermont from 1935 to 1937 and Assistant Hydraulic Engineer, Corps of Engineers, Upper Mississippi River Navigation Project from 1937 until 1940. He was in charge of review of navigation and flood control programs as a Hydraulic Engineer with the Corps of Engineers at their Upper Mississippi Division office for three years before World War II and four years thereafter. He was in the Civil Engineer Corps, U. S. Navy designing and constructing advance bases in the Pacific during the War years.

For the past eleven years Mr. Eden has been in charge of Planning and Hydraulic Design, Corps of Engineers, Jacksonville, Florida, for planning the Central and Southern Florida Flood Control Project.

Mr. Eden's professional societies include American Society of Civil Engineers, Permanent International Navigation Congress, American Geophysical Union, National Society of Professional Engineers, International Commission on Irrigation and Drainage, and U. S. Council on Wave Research.

He is a registered land surveyor in New Jersey and a registered engineer in Florida.

and last, the inland movement of salt water in canals and porous underground aquifers.

In this paper, the results of studies made by the Jacksonville District of the Corps of Engineers during the planning and design of the Central and Southern Florida Project will be summarized. The planning investigations were initiated by a compilation of the available data which were correlated and analyzed in accordance with the usual hydrologic statistical practices. Development of design criteria required considerable interpretation because available field data were largely limited to the period since 1930; however, some isolated records—particularly rainfall —extend as far back as May 1851 when the collection of data began at Fort Meade. The Fort Meade rainfall record was discontinued in 1920. It is quite probable that the available records will be broken in the future—some of them many times. It is considered probable that greater variation in the data will be found in those estimated for short time periods, although the short-period records appear to be consistent with the records for longer periods. There is a distinct need for continuing and augmenting the existing programs of data collection. As the region develops, there is an increased need for improved planning of the uses of water resources. The time has passed when Florida has excess water to waste; although with proper use, the supply should be adequate for any foreseeable need. There is also a need for improved control of water elevations, so that interference with other waterfront developments is held to a minimum. It will be only by increasing the accuracy of our basic data that water resources projects can be constructed, operated, and maintained to best meet the needs of the area. I will start my discussion of the problem by considering the factors associated with estimating the volume of excess runoff. As mentioned earlier, data on rainfall have been collected in this area since May 1851. However, in 1925 there were still only about 30 rainfall stations in operation in or adjacent to the area affected by the Central and Southern Florida Project. At present, the number has increased to many hundred. It is difficult to estimate exactly how many rainfall stations now exist because data are or have been collected by many agencies—local, State, and Federal, as well as private individuals and companies—for many purposes.

The average annual rainfall varies from about 74 inches at Okeechobee City, representing the interior of the State, to about 65 inches at Boca Raton along the Coast. In the Central and Southern Florida Project area, the highest annual rainfall of record at a single station is 136.23 inches observed at Delray Beach in 1947. The lowest annual rainfall of record at a single station is 18.27 inches observed at Ft. Meade in 1853. The lowest annual rainfall observed in recent times is 26.67 inches recorded at Belle Glade in 1939. The most intense rainfall ever recorded within the area is 21.92 inches in 24 hours at Canal Point Breeding Station, with most of the rainfall occurring between midnight and noon on November 7, 1932. The maximum 24-hour rainfall observed in the State occurred at New Smyrna in October, 1924 when a total of 23.22 inches of rainfall was experienced.

In the planning studies for the project, the maximum 24-hour rainfall that could be expected at various exceedence frequencies was computed, together with the relation between 24-hour and other rainfall durations. The maximum 24-hour rainfall amounts that can be expected to be

equalled or exceeded once in 10 years and once in 100 years are shown on plates 1 and 2. The relationship between the 24-hour rainfall and that which can be expected over longer periods is shown on plate 3.

The quantity of water which control works are required to store, convey, and/or discharge is the rainfall less any losses which are primarily: evaporation from free water surfaces, the evapo-transpiration of growing vegetable matter, and seepage from and to underground aquifers.

All water surfaces gradually lose water vapor to the atmosphere at a rate depending on exposure. The U. S. Weather Bureau, the Corps of Engineers, and other agencies operate evaporation pans at a number of sites within the area. The average annual observed evaporation over Lake Okeechobee from a Colorado-type sunken pan has varied from 44.2 to 67.6 inches with an average of about 55.6 inches. Investigations made by the Bureau of Reclamation indicate that the observed pan evaporation from a Colorado-type sunken pan should be multiplied by 0.79 to obtain the evaporation from a large open body of water. Hence, this would be roughly equivalent to a loss of from 35.0 to 51.5 inches annually from Lake Okeechobee or from any other water-storage area in the region.

The evaporation can be expected to vary seasonally. In the vicinity of Lake Okeechobee, the monthly losses from the Colorado-type pan were as follows:

	Observed evaporation (inches)		
Month	Maximum	Minimum	Average
January	4.0	1.8	3.0
February	4.7	2.8	3.6
March	6.9	3.7	5.0
April	7.4	3.9	5.7
May	8.3	3.2	6.3
June	8.8	3.4	5.6
July	9.0	3.8	5.4
August	7.2	3.6	5.4
September	6.1	3.5	4.5
October	6.2	2.2	4.5
November	6.0	2.5	3.7
December	4.3	1.8	3.0
Annual	67.6	44.2	55.6

The most important consumption of water is that used by growing plants, which is called evapo-transpiration. The consumption varies with the type of vegetation, soil type, and other factors including the adequacy of the water supply. However, plants have the ability to adjust their consumption of water within a wide range when the available water is less than required for optimum growth. This makes it quite difficult to measure directly the evapo-transpiration requirements because evaporation pan observations do not duplicate the conditions that can be expected in nature.

In the central Florida area, it is possible to estimate the loss by empirical relationship developed from very carefully controlled experiments. Blaney and Criddle of the U. S. Department of Agriculture have expressed consumptive use by vegetation, or evapo-transpiration, by the formula:

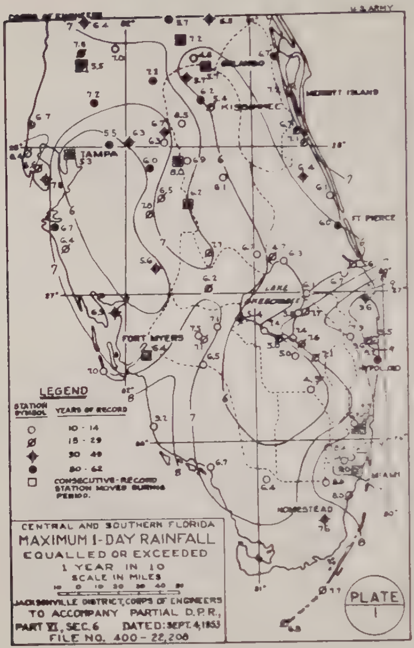


Plate 1.

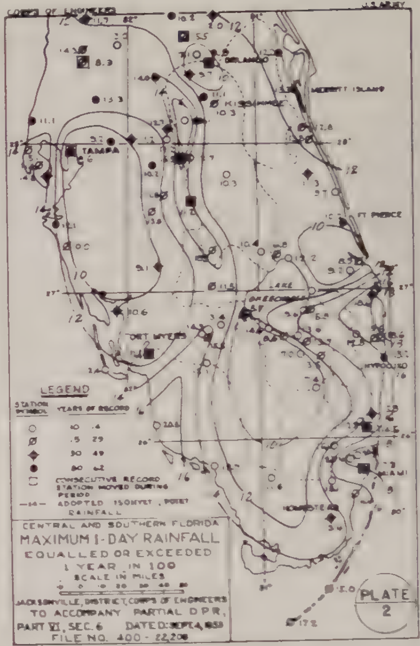


Plate 2.

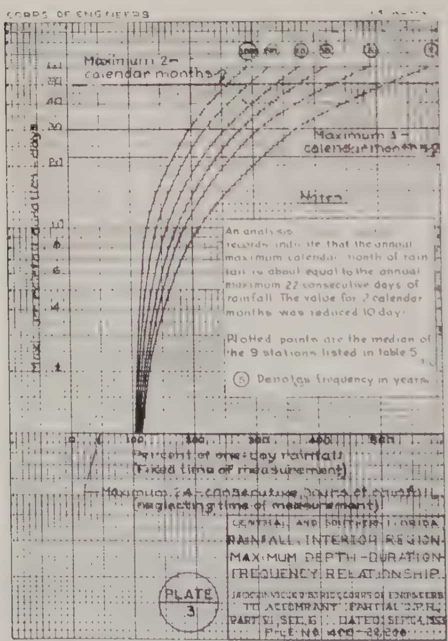


Plate 3.

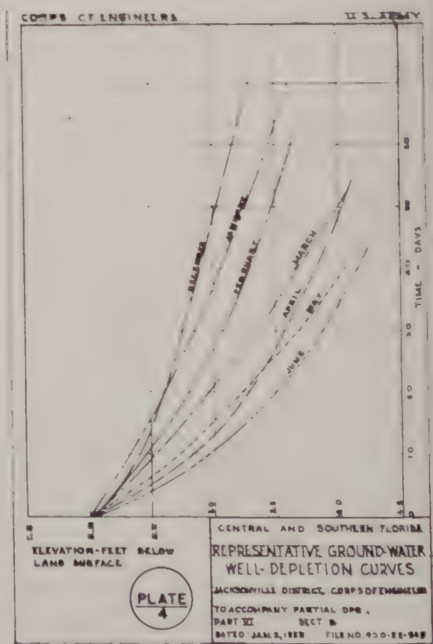


Plate 4.

U = KF, where:
U = consumptive use, in inches, over a given period t
F = mean temperature, in degrees Fahrenheit, during t, multiplied by the ratio of the sum of daylight hours in period t to the sum of the daylight hours in a year for that latitude.
K = consumptive-use coefficient (determined experimentally for a particular crop during its period of growth)

The value for "F" in the general latitude of Kissimee River is about 73. From the Blaney and Criddle experimental determination of "K", which would apply to various crops, it is estimated that "K" for this area would be about 0.60. Under those conditions, it is computed that the average evapo-transpiration consumption would be about 45:0 inches or slightly less than the average annual rainfall.

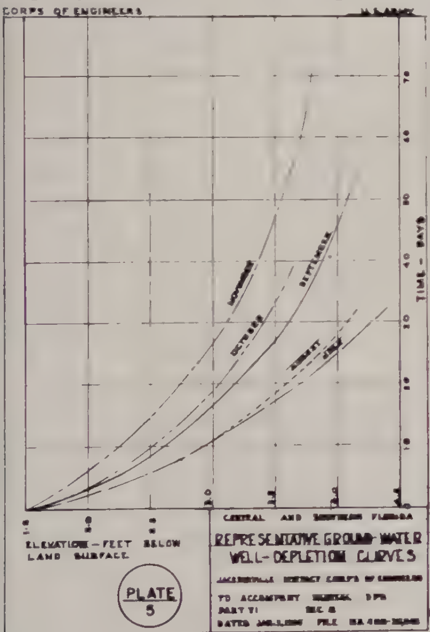


Plate 5.

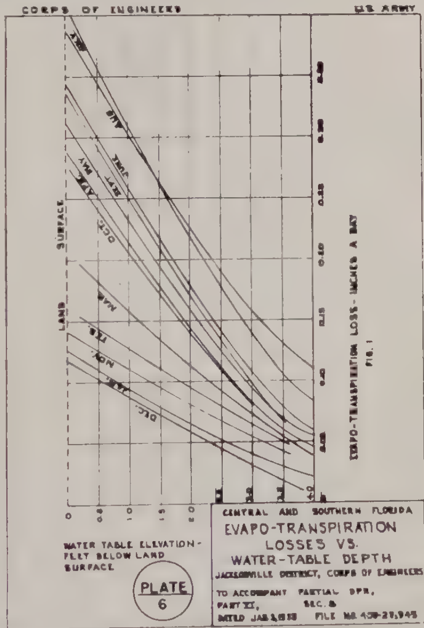


Plate 6.

It is also possible to estimate the evapo-transpiration consumption from the ground-water hydrographs. During periods of little or no rainfall, growing vegetation obtains the moisture required from water in ground storage. This causes the water levels to gradually recede. Observations under controlled conditions indicate a loss of 1 inch will lower the ground water in the soil about 5.5 inches. Typical ground-water well depletion curves are shown on plates 4 and 5. Analysis of the records indicates that ground-water levels are responsive to evapo-transpiration and to rainfall, especially in flat areas. In high land areas, the depth to the water table becomes important and the hydrographs are not so pronounced, particularly where the ground-water table is located at some distant point from the surface. The estimated daily evapo-transpiration for each month of the year and variations in ground-water depth

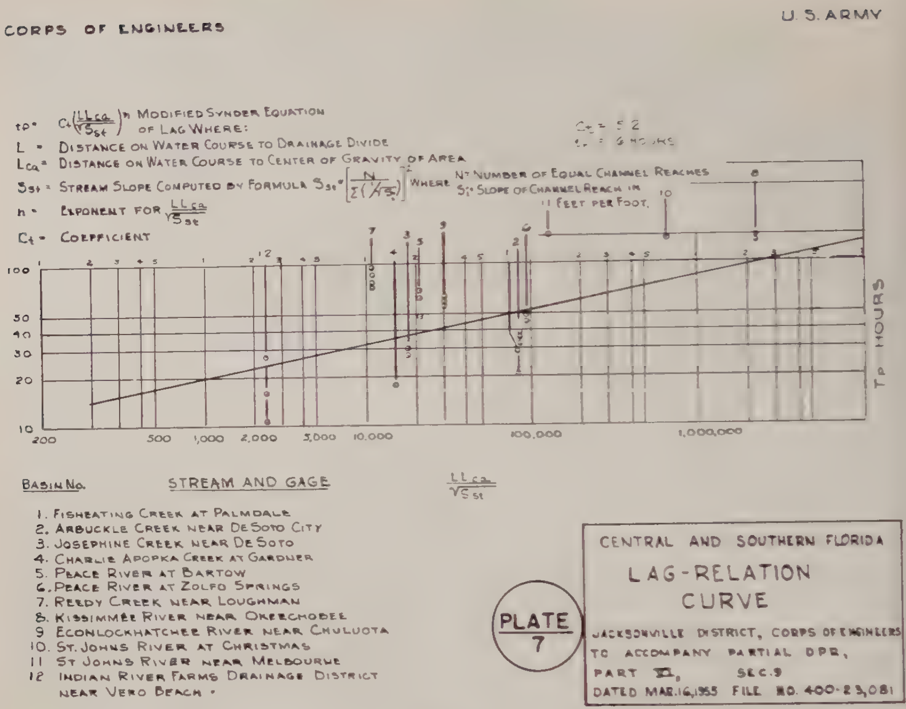


Plate 7.

are shown in plate 6. In those records, the effect of subsurface lateral flow has been eliminated. The evapo-transpiration can be expected to vary from a maximum of 6.11 inches in August to a minimum of 1.24 inches in January with an average annual consumption of about 37 inches. The computed monthly average evapo-transpiration values are given in the following table.

ESTIMATED EVAPO-TRANSPIRATION LOSSES FOR CENTRAL FLORIDA

Month	Daily loss (inches)	Monthly loss (inches)
January	0.040	1.24
February	0.061	1.71
March	0.062	1.92
April	0.068	2.04
May	0.082	2.54
June	0.108	3.24
July	0.154	4.77
August	0.197	6.11
September	0.177	5.31
October	0.153	4.74
November	0.075	2.25
December	0.043	1.33
Total		37.20

There are experimental data that can be used as a check on the data deduced from this analysis. The Soil Conservation Service has a program in the Indian River Farms Drainage District to evaluate water use and losses. Analysis of data obtained in that program indicates the average annual evopa-transpiration losses in this area, from the SCS data, to be 37.60 inches a year.

Whenever the volume of rainfall exceeds the losses due to evaporation, evapro-transpiration, and seepage, there is excess water which can be either stored in surface ponds or depressions or discharged from the area as runoff. The time distribution of the runoff will vary with the topography, shape, and size of the drainage area; the development of the drainage pattern; and other factors. The most direct approach to estimating the time distribution of the runoff is by analyzing observed hydrographs from the sea. In the preparation of design criteria for facilities provided under the Central and Southern Florida Project, all the discharge records available within and adjacent to the project area were examined. It was interesting to note that the analysis had to be concentrated at 12 discharge gauging stations which were of sufficient length and accuracy to warrant detailed examination. It is believed that this indicates the definite need for a more comprehensive data collection program. It is well that the data collection program be general rather than related to any particular project, because if the records are not available when a project is initiated, it is too late to initiate such a program. The program would have to be continued over sufficient time to insure representative conditions before it could be used with any degree of reliance. In a rapidly developing area such as Florida, the runoff-producing characteristics of the area can be expected to change. It is thus highly desirable to continue the data collection as long as possible to insure that the estimates accurately reflect the distribution of runoff which the project is expected to handle.

In determining discharge criteria for the Central and Southern Florida Project, the unit hydrograph approach was used. That is the determination of the time distribution or hydrograph of the runoff which would result from 1 inch of excess rainfall occurring in 6 hours. Where rainfall over that duration was responsible for the runoff, the observed unit hydrograph was adjusted by use of established procedures. The observed unit hydrographs were analyzed by determination of the basic unit hydrograph factors in accordance with the work done by Snyder. Three basic parameters were used to define the unit hydrograph in terms of basin characteristics. Lag—as defined by Snyder—is the time from the center of mass of effective rainfall to the peak of the unit hydrograph. This factor provides an index of watershed characteristics. This has been determined to vary in accordance with the following relationship:

$$t_p \text{ or lag time (in hours)} = C\ (LL_{ca})\ 0.3.$$

where C_t = coefficient of watershed characteristics

L = distance, in miles, from the gauging station to drainage divide, measured along main channel

L_{ca} = distance, in miles, from the gauging station to a point opposite center of gravity of the drainage area.

The relationship has been modified for considering basin slope by Linsley, Kohler, and Paulhus, as follows:

$$t_p = C_t \qquad \frac{LL_{ca}{}^{n}}{s}$$

where s = the basin slope in feet per foot.

Since the slopes encountered in central Florida are usually quite flat, the main stream slope, S_{st}, has been substituted for s in these studies. Examination of the streamflow data indicated that 0.2 could be substituted for n in the equation for this area.

The second characteristic is the relationship between the peak flow, q_p, in c.f.s. per square mile, with the lag, t_p. Snyder determined that the q_p would vary in accordance with the following equation:

$$q_p = \frac{640\ C_p}{t_p}$$

where C_p is a characteristic of the watershed. In central Florida, it was found to vary from 0.19 to 0.70 with an average of about 0.40. The variation of q_p with t_p for the area under consideration is shown on plate 8, using an average value of 0.40 for C_p.

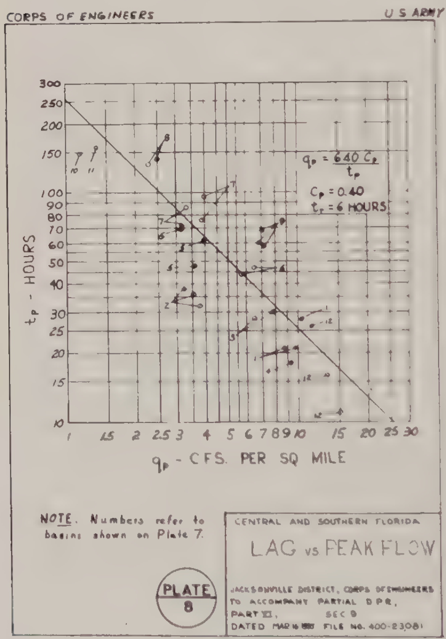


Plate 8.

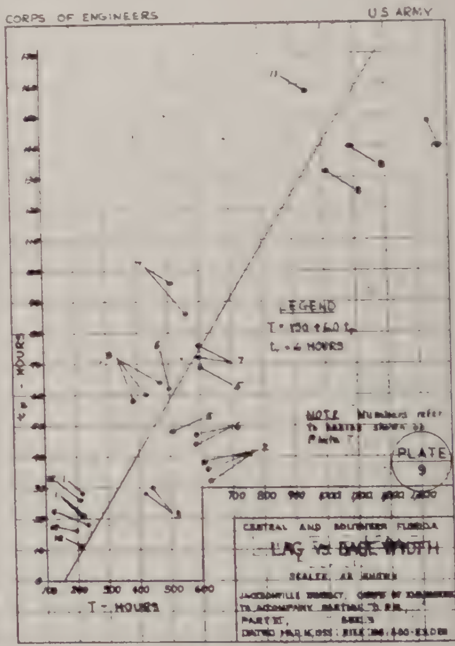


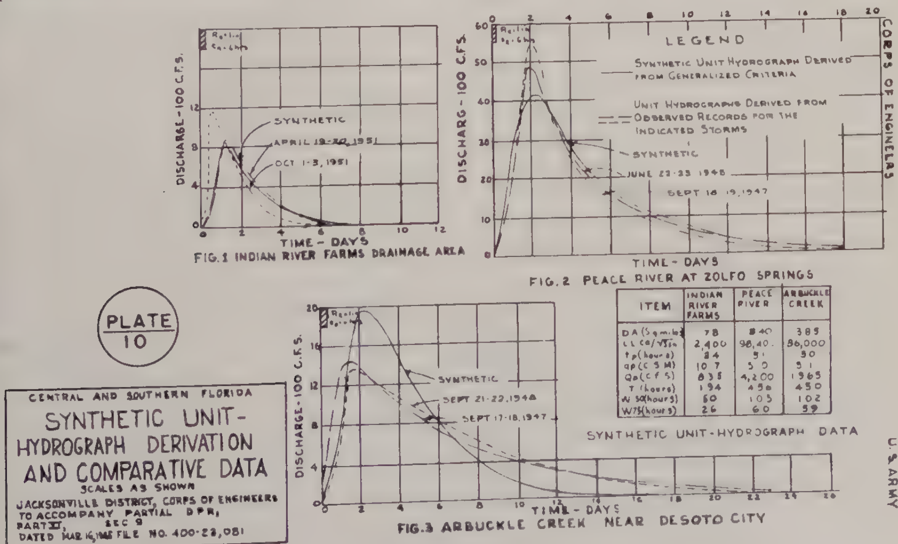
Plate 9.

The third characteristic of the unit hydrograph used for comparison was the relation of base width to lag. This was also made in accordance with data developed by Snyder. Examination of the data obtained in this area shown on plate 9, indicates that T, or base width, in hours = 150+6 t_p. This is somewhat greater than that found in other areas where average basin and channel slopes are greater and the stream pattern has been more fully developed.

In order to demonstrate the application of the generalized character-

istics to develop synthetic unit hydrographs, they have been applied to several basins for which actual unit-hydrograph data are available. Those areas are the Indian River Farms Drainage area on the east coast, the Peace River watershed in the upland area just west of the Kissimme River Basin, and the Arbuckle Creek area in the Kissimmee River Basin. Those areas represent range of topographic characteristics and degree of drainage development that can be expected in the project area. The comparison is shown on plate 10. The comparison between the synthetic unit hydrographs and those on observed flows is not as close as is considered desirable. However, the generalized factors represent average conditions, and some deviation would be expected. In areas where existing drainage facilities are inadequate—such as found on Arbuckle Creek and many other Florida streams—the synthetic unit hydrograph would tend to show a characteristic flat peak and longer duration of flooding. In steeply sloping areas, such as Peace River Basin, the converse might be expected. It was therefore considered that with further development of the areas, and improvement of the drainage facilities, the runoff characteristics of most central Florida streams would approach those indicated by the generalized relationships. With additional basic streamflow records, these relationships can be refined with improvement in the estimates of the distribution of discharge for streams in this area.

The second group of hydraulic and hydrologic criteria are those required to evaluate and estimate the effects of winds or reservoirs and conservation areas. Florida is located in an area which is exposed to hurricane at rather frequent intervals during the period from 15 June to 15 November . Examination of the records since 1900 indicates that from 1901 through 1959 there were 22 hurricanes with winds over 75 miles an hour that crossed the coast of Florida. Several additional ones including Donna and Florence passed over Florida this year. Of those, 18 passed within 50 miles of Lake Okeechobee and the conservation areas provided under the project. That is near enough to significantly affect



ITEM	INDIAN RIVER FARMS	PEACE RIVER	ARBUCKLE CREEK
DA (Sq.mi.)	78	840	385
LLca/√S	2,400	98,40.	86,000
tp (hours)	34	51	50
qp (CSM)	10 7	5 0	5 1
Qp (cfs)	835	4,200	1965
T (hours)	194	456	450
W 50 (hours)	60	105	102
W 75 (hours)	26	60	59

Plate 10.

the water elevations, and be potentially dangerous to adjacent property.

Analysis of the hurricanes of record provides information that can be used in the design of facilities to reduce the damages that have accompanied these severe storms in the past. The project area is exposed to hurricanes originating in either the Atlantic Ocean or Gulf of Mexico, of about equal frequency. However, the records indicate that those which approach from any path between northeast to southeast tend to be more violent over Lake Okeechobee and the conservation areas. The estimated maximum winds, over a 10-minute period of the storms experienced within 50 miles of Lake Okeechobee, have varied up to 112 miles per hour. The effect on the water surface such as Lake Okeechobee is a factor of the radius of the maximum winds, and the central pressure. Analysis of all the available data indicated that the most violent storm than can be expected to affect Lake Okeechobee would have an average velocity over a 10-miute period of about 95 m.p.m. with a central pressure of about 26.75 inches of mercury. In order to exert maximum influence on the lake, the radius of maximum wind would be about 13.0 miles. The largest storm that could be reasonably expected to affect the lake was estimated to have an average velocity over 10 minutes of about 85 m.p.h. with a radius of maximum winds of about 30 miles and a central pressure of about 27.50 inches of mercury. This storm has been considered the design hurricane for project works.

The early residents of that part of Florida learned to fear wind tides—perhaps more than the winds themselves. In addition, a lack of clear understanding of the phenomenon has resulted in even higher property damage and in human injury and death. It was in order to obtain some security from the hurricane-driven wind tides that the first levees around Lake Okeechobee were constructed. That levee system has been enlarged and improved several times until it now affords the area practically complete security from this hazard.

In order to design the enlargements which are necessary when the operating levels are raised, more detailed information and design criteria were needed. Since this is almost a unique problem, isolated to only a few sections of the world, hydraulic and hydrologic data were collected around or on Lake Okeechobee. The data collection consisted of instruments to measure barometric pressure at several levels above the lake, wind speed and direction (also at several levels), water stages, and temperature, rainfall, wave heights, and many other factors that were considered important in estimating the behavior of a free water surface under the force of wind. In the analysis, the Corps of Engineers was assisted by outstanding engineers and students from many universities, the Weather Bureau, the Bureau of Standards, and several other agencies.

Data were collected from the hurricanes of September 15-16, 1945; September 17, 1947; September 22, 1948; August 1949; and October 1950. Collection of this type of information is frustrating because the system was in operation many years when Florida was fortunate in not being exposed to a hurricane. A basic relation was derived from the data which indicated that the setup, or rise above mean water level, is

$$h_s = \frac{N T_{sp} F}{64.4_D}$$

where T_s = Tangential stress caused by the wind on the free surface (lb./ft.2)
F = fetch from windward to leeward shore (ft.)
P = plan form, factor to evaluate the effect of the angularity of the shoreline
D = water depth (ft.)
N = factor related to h_s/D

The setup or wind tide varies inversely with depth, which accounts for the major problem at Lake Okeechobee, where the mean depth is only about 11 feet, and along the shallow coastal lagoons which encircle the mainland of Florida. This research has greatly improved the reliability with which facilities to protect property adjacent to coastal and inland areas can be designed.

Another phenomenon which is of importance in the design of structures adjacent to Lake Okeechobee and the conservation areas is the formation of waves. As both wind setup and waves are produced by wind action, the occurrence of the maximum waves coincide in time and duration with the wind setup. In shallow bodies of water, the depth of the water and the characteristics of the bottom will also affect the height and characteristics of the wave formation. In the planning of works for Lake Okeechobee, wave guages were used to obtain information on the waves that occur under various conditions. Information was collected on several hundred thousand individual waves during the 1949 and 1950 hurricanes ,of which about 50,000 were studied in detail. During the 1949 hurricane, waves as high as 8.3 feet were observed. 75 percent of the wave height was found to be above the stillwater level for this wave. The wave period is the time interval between two or more successive waves of approximately the same period, and of prominent height. The analysis indicates that the physical upper limit of the wave period for waves over 2.0 feet in height in Lake Okeechobee was about 6 seconds In addition to the field observations, a study was made at the University of California to study the characteristics of wind-generated waves. With the field and laboratory data, it was possible to establish criteria that are used to determine the wave action that can be expected on any portion of the lake shore during a storm or hurricane. At hurricane Gate Structure No. 5—at Canal Point on the east shore of the lake—it was estimated that waves from 9 to 15 feet and a significant wave period of between 6.5 and 8 seconds may be expected during the occurrence of the design storm.

Waves striking any shore structure expend a portion of their energy on a vertical translation of a part of their mass upward. If the structure is a levee, the movement occurs along its exposed slope as can be observed any day at the beach. The height to which the water rises above the stillwater level is known as "runup." If water rises above the protection afforded by a levee, "overtopping" occurs. Overtopping to a significant extent has been a major factor in most levee failures in other areas. On Lake Okeechobee, however, there has not been significant overtopping of the existing levee protective works since their construction in 1931. The difficulty of collecting field information is illustrated by the effort made in this field. A field runup gauge, where visual information as to the height waves ran up the slope, was established on the north shore of

the Lake Okeechobee levee system in 1953. Since installation of that gauge, no appreciable runup has occurred at that point.

Due to lack of any field observations, it was necessary in design work under the project to utilize data collected in the laboratory with model levees.

In order to check the model results and to eliminate any scale effects, four laboratory studies were made: two separate model studies at the United States Waterways Experiment Station at Vicksburg, Miss., one at the Beach Erosion Board in Washington, D. C., and another at the University of California Wave Research Laboratory. Analysis of the results indicated the significant influence of the slope of the levee. For example, at Hurricane Gate Structure No. 5, the wave runup expected would vary as follows:

Levee slope	Range in runup (ft. above wind-tide elevation)
1 on 3	18.0 to 27.0
1 on 6	7.0 to 11.0
1 on 10	3.6 on 6.0

It can be seen that these factors are very important in the safe and economical design of facilities required to store water in this area or any other area affected by excessive winds.

The third group of problems arises from the natural characteristics of this area and are related to the growth of plants under a moist sub-tropical environments. As we are aware, very thick luxuriant growth can be expected, particularly on lands such as are found in the Everglades. Within the Central and Southern Project, those lands are used to convey excess water southward to the Gulf of Mexico through the Everglades National Park and, in some areas, to conserve available water to meet expected requirements from several months to several years later. In order to properly design water control facilities, it was necessary to evaluate the movement of water through the marsh grasses under the forces of gravity and also under other forces such as wind.

The Everglades are quite flat under natural conditions. It is possible to start northward through the Glades and find that the water depth remains almost unchanged. For example, if about 1 foot of water was found at Tamiami Trail, the water would still be about 1 foot deep 15 or 20 miles north of the Trail although the ground had risen between 1 and 2 feet. However, close inspection indicates that the water is moving slowly toward the south, or downslope at velocities as low as 0.01 foot per second.

At Tamiami Trail, the U. S. Geological Survey has measured the discharge through the Trail for many years. Using these data, it is possible to determine the roughness coefficient required to duplicate the rating curve by backwater computation. While it was recognized that the formula could not be applied directly to the movement of water by laminar flow, it does provide a comparison with the coefficients generally used in Manning's formula under turbulent discharge conditions. The resistance coefficient required to duplicate the rating curve was 1.30, compared to the 0.025 to 0.050 generally found in reasonably maintained open channels.

In order to more nearly define the resistance of vegetation on the flow, a system of gauges was established in the Everglades. They provide 60-day records of rainfall and water stage. Preliminary analysis of data collected indicate that a resistance factor somewhat less than that developed at Tamiami Trail may apply to vegetated areas—something perhaps from 0.30 to 0.60. However, the collection of basic data is continuing since more data are required for precise computation.

The movement of water under wind action is even more difficult to define, although it would probably be subject to the same general resistance from the vegetation which impedes the discharge of water under forces of gravity. There is one additional effect, since the formation of wind-tide setup and waves is due to the force of the wind acting on the surface of the water. If vegetation protrudes through and above the water surface, the force of the wind acting on the water surface is greatly reduced, and in some cases eliminated. A detailed study of past hurricanes failed to indicate a single instance of where hurricane winds had created a wind-tide against a road embankment or any other type of impediment to the movement of water. Old residents could not recall an instance when U. S. Highway 27 from Belle Glade to Miami, Tamiami Trail (US 41) from Miami across the Glades, or any other highway having been overtopped as the result of wind tide. In the design of conservation areas, these empirical data have been co-ordinated in the development of the plan of regulation that will insure that the existing vegetation is maintained. This is one point where the services of plant botanists have been used to develop safe and economical works.

The last group of problems discussed in this paper is those related to the movement of density currents in canals and porous underground strata. These data are of importance in the design of work, to reduce or eliminate the encroachment of saline waters in coastal areas. In open bodies of water such as canals and natural streams, there has been considerable research on this factor. This research has extended to the area of greatest hazard within Florida—the Miami area—and also to studies by the Bureau of Standards in Washington, and by other agencies and individuals. The encroachment of salt water may occur in a canal and stream when the heavier salt water moves inland as a density current along the bottom. It may move upstream in a canal or natural stream even while fresh water is being discharged in the reverse direction at the surface. This is particularly true in streams of this area where water slopes are quite flat.

The results of field and office studies indicate that the movement of the higher density water can be arrested at a control structure if a fresh water head equal, to the difference in specific gravity is maintained. In general, a head of 1 foot will be adequate to balance a depth of 40 feet of saline water having an approximate density of 1.025. In the Miami area, the Biscayne aquifer varies from 100 to 125 feet in thickness near the coast so that about 2.5 feet of fresh-water head is required to prevent the movement of the saline water at the base of the aquifer.

There are other factors of importance in hydrologic and hydraulic design but those discussed have been the most important in the planning and design of the water-control facilities provided under the Central and Southern Florida Project. The development of the criteria for this project has required the effort of many people. In addition, the development of

several criteria required laboratory work. It is important that the collection of data be contained so that the facilities provided can be adjusted to provide the best degree of protection and further to furnish information on effect of development, so that the project works can be modified to meet the needs.

The data discussed have been developed in the Planning and Reports Branch of the Engineering Division of the Jacksonville District, Corps of Engineers with the advice and guidance of the South Atlantic Division and the Office of Engineers. The District Engineer of the Jacksonville District is Colonel J. V. Sollohub; Chief of the Engineering Division is Mr. Joe J. Koperski. I want to particularly acknowledge the work of Messrs. Oscar Rawls, Lawrence Farrer, Angelo Tabita, Charles Chambliss, and other members of the Planning and Reports Branch of the District whose efforts were responsible for the developments discussed.

Ground Water in the Central and Southern Florida Flood Control District[1]

Gerald G. Parker[2]

INTRODUCTION

This report is based chiefly on the results of investigations made by the U. S. Geological Survey of the geology and water resources of southern Florida. Most of the work has been accomplished in cooperation with the Florida Geological Survey, the Central and Southern Florida Flood Control District, and in joint cooperation with the Cities of Miami, Miami Beach, Coral Gables, and Dade County. Other governmental agencies and groups have contributed to these investigations, chief among them are the Corp of Engineers, the Soil Conservation Service, and the Agricultural Research Service.

Cooperation with the Florida Geological Survey began about the turn of the century, but it was not until after the second world war that this cooperation was of a scope sufficient to provide a large-scale investigation of the water resources of the state.

Cooperation with the Central and Southern Florida Flood Control District began shortly after that agency was established by the Florida Legislature in 1949. Since then a number of county investigations have been accomplished and some are still in progress; reference is made to these later in the text and in the bibliography.

The joint cooperation with the cities Miami, Miami Beach, Coral Gable and Dade County, begun in 1939, was the basis for one of the most intensive and comprehensive water resources investigations ever made by the U. S. Geological Survey. Out of this study about twenty-five reports

[1]Published with the permission of the Director, U. S. Geological Survey.

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Mr. Parker was born in Leona, Oregon in 1905. He received his Bachelor of Arts degree from Central Washington College of Education and his G.S. from the University of Washington.

Mr. Parker began his professional career teaching and administering in the public schools of the State of Washington prior to assuming the position of Junior Geologist to the District Geologist, U. S. Geological Survey, Miami, Florida. Since assuming those duties he has advanced in rank in the U. S. Geological Survey to Principal Geologist and Chief of the Soil and Moisture Conservation Program (Arid Regions Hydrologic Investigations), General Hydrology Branch, Denver, Colorado.

He has approximately thirty-five publications to his credit in several fields of geology and hydrology. Notable among these having a Florida theme are "Effect of the Pleistocene Epoch on the Geology and Ground Water of Southern Florida" and "Water Resources of Southern Florida."

Mr. Parker is a contributor of articles to *Encyclopedia Americana*, and to the *World Book Encyclopedia*.

His professional and honor society memberships are American Association for the Advancement of Science; American Association of Petroleum Geologists; American Geophysical Union; Geological Society of America; Geological Society of Washington (D. C.); Philosophical Society of Washington (D. C.); Society of Economic Geologists; Phi Delta Kappa; and the Cosmos Club.

were published, of which Water-Supply Paper 1255, published in 1955, entitled the "Water Resources of Southern Florida," is the principal publication. Comprising 956 pages, 24 plates, 223 figures and 147 tables, it is the report commonly referred to as "the bible" for this area.

In addition to the cooperative work mentioned above, the Survey has engaged in numerous smaller-scale investigations of county-size areas, or for specific purposes such as road and culvert design, with a number of cities, drainage districts, State agencies and others. Chief among these have been the Florida State Road Department, the Florida State Board of Health, the Everglades Drainage District, the Okeechobee Flood Control District, the Lake Worth Drainage District, the Univerity of Florida Agricultural Experiment Stations, the Trustees of the Florida Internal Improvement Fund, and the Cities of Fort Myers, Fort Lauderdale, Dania, Fort Pierce, Lake Worth, and Delray Beach.

Many individuals, too numerous to mention, have been responsible for getting much-needed investigations started, or have given generously of their time and effort in support of these studies. The U. S. Geological Survey is especially indebted to the following: Herman Gunter and Robert O. Vernon of the Florida Geological Survey; A. P. Black and Joseph Weil of the Univerity of Florida; ex-Mayor Alexander Orr, Jr., of Miami; Malcolm Pirnie, Consulting Engineer, New York City; W. Turner Wallis, formerly Chief Engineer of the Everglades Drainage District and later of the Central and Southern Florida Flood Control District; Robert V. Allison of the University of Florida Experiment Station at Belle Glade; and John C. Stephens of the Agricultural Research Service, Fort Lauderdale. Many others, including consulting engineers, city managers, well-drillers, municipal and county engineers have been of inestimable help. To all who have in any way helped in gaining a better understanding of the geology and water resources of this area the Survey is most grateful.

WATER PROBLEMS

In common with the rest of the United States, Florida is beset with certain water and associated problems, and all of these problems are people-related, because without people to be affected there would be no problems. However, since there are people, and people are affected, the problems exist and some of them are most complicated and difficult to resolve.

A brief consideration of these problems follows. It will help to set the stage for the discussion of the ground-water resources, which is the main topic of this paper.

Water problems may be divided basically into two categories: (1) those caused by effects of natural phenomena, such as differences in geology, floods or droughts, and changing sea level; and (2) those caused directly by man's activities, such as occupancy of flood plains, drainage operations, and dumping his wastes into nearby streams. Problems of the first category are concerned with identifiable entries or trends, although to ascertain all the relevant facts may be quite costly in terms of time, money, and the efforts of highly trained specialists. Problems of the second category change as man's population, land occupancy, and his activities increase or grow more complex. Whereas the problems of the first category require the services of physical scientists and engineers, prob-

lems of the second category require largely the services of economists, consulting engineers, industrialists, lawyers, politicians or statesmen, and management personnel of several levels of operations. Their decisions and actions taken to alleviate or correct water problems, if they are to be successful, must be based upon an adequate understanding of facts related to pertinent natural phenomena.

A generation or two ago, in most areas of the United States, we were faced largely with problems related chiefly to natural phenomena; now, in addition to these, we are confronted almost everywhere, in increasing amounts, with people-caused problems. Problems related to the first category are more or less constant in character; for instance, if it is a problem of defining an aquifer's boundaries, or its storage and transmissability characteristics, or a stream's annual flow, these either do not change with time, or change within definable limits. But problems of the second catagory do change, and often greatly, with time, and they seldom become less serious; for example, there are not only more people now to use water but these people demand much more water per capita than their immediate ancestors did. Water-use requirements do not increase arithmetically as does population—it tends to increase geometrically, or at some other rate greater than the population. A simple, agricultural-centered economy, such as existed here in the 1930's might have gotten along well on less than 100 gallons per day per person. Now for our modern, complex, industrial-agricultural society we require many times that amount. Recent U. S. Geological Survey estimates are in the order of 1,500 gallons a day per person, the country over. The per capita use here in Southern Florida is not known, but it probably is less than half the national average quoted above.

Here in Southern Florida our water problems were first those concerned with drainage. And, without knowing enough (and doubtless many caring less) about the problems involved, the costs related thereto, or the consequences of their actions, the drainage enthusiasts set to draining the surface waters from this part of the state. We, here, are cognizant of the errors and unfortunate results of most of those actions, thus neither time nor space will be taken here to recount them in detail.

It is doubtful that the drainage enthusiasts ever envisioned that, among other results of their operations, they would induce or cause:

(1) Shrinkage, compaction, oxidation, burning, and general subsidence of the organic soils. This loss is reported by Jones (1948, p. 79) to be as much as 5 feet over extensive cultivated areas. In some places, where the organic soils were a couple of feet or less in thickness they have disappeared completely.

(2) Development of wide, shallow "subsidence valleys" along each drainage canal in the muck and peat soils (Evans and Allison, 1942, p. 34-36).

(3) Increase frost damage, which formerly had been held in check by the large body of water in the Everglades (Clayton, Neller, and Allison, 1942, p. 5).

(4) Reduce the original capacity of the canals, thus contributing to floods, slowing down of runoff, and general canal inefficiency. This resulted from soil-compaction and burning, thus lowering the land surface near the canals and reducing the vertical heights of the banks;

slumping of canal banks; and blocking of canal flow by water weeds, fallen trees, and other debris.

(5) Cessation of the processes that had built up the muck and peat soils in the first place.

(6) Changed ecologic conditions seriously affecting wildlife of the drained areas. This has resulted in species migration and the extinction, or near extinction of others—one of these is the Everglades kite, now a rarity because of the drainage of the swamp with resultant destruction of a certain species of fresh-water snail upon which the kite feeds solely (O'Reilly, 1940, p. 129, 131-134).

Water problems have become of prime importance. Whereas we in this area were first concerned only with getting rid of water, or practicing flood control, we now are greatly concerned with:

(1) The development, and protection from salt-water contamination, of adequate perennial supplies for the populous cities, and for the agricultural areas along both the Atlantic and Gulf coasts.

Southern Florida is currently experiencing one of the fastest-growing population expansions in the world. Data are not at hand to document the extent or rate of population growth in the area that is contained in the Central and Southern Florida Flood Control District, but the U. S. Census Bureau was recently quoted in the *Washington Post* and *Times Herald* (Nov. 16, 1960, p. B-4) on population changes in Florida during the last decade as follows:

1960 Population	1950 Population	Persent Increase
4,951,560	2,771,305	78.7

There are no signs of this population-expansion trend diminishing. One must conclude, therefore, that demands for water supplies will continue to increase at an ever-growing rate, and that the salt-water problem will become increasingly alarming and more acute as more water is pumped in the coastal areas and as more canals and waterways, connecting with salt water of the ocean or bays, are dredged.

(2) Unregulated, or improperly regulated, canal flow. In those canals that are tidal, salty ocean water moves inland in and along the lower reaches of the canals, even beyond the Atlantic Coastal Ridge in some places, thus contaminating the fresh-water aquifers in areas adjacent to the canals, or allowing a broad-front advance in the aquifers in inter-canal areas.

Salt water was observed 11 miles inland in the Miami Canal in 1939. During the Spring of 1945, salt water was noted seeping into the canal bottoms that were above the receded water table of such drought-ridden canals as Biscayne and Little River Canals near their western ends, east of Red Road (Parker *et al*, 1955, p. 630).

(3) Changes in salt-water—fresh-water balances. This is a two-pronged problem. One is the result chiefly of the dredging of canals to drain the Everglades. This has resulted in lowering the fresh-water head under the Coastal Ridge in places as much as five feet. This alone has upset nature's long-established equilibrium and caused an inland movement of salt water in the Biscayne aquifer in a broad front all along the coast in the entire area affected by lowered levels (Parker *et al*, 1955 p. 589).

The other is a rise in sea level, believed to be eustatic and in response chiefly to increasing wastage of land-locked glacier ice. Marmer (1941

and 1949) has reported on this phenomenon, and Parker (1955) has related this rise to effects on coastal water supplies. Until 1930 sea level was gradually but very slowly rising, but since 1930 a sharp rate of increase has been noted. Sea level along the Florida shore has risen more than 6 inches since 1930, which is at an apparent rate of about two feet a century. If this rate of rise continues, or increases, our salt-water encroachment problems, shoreline erosion problems, drainage of low-lying coastal areas, and other related conditions will rapidly worsen.

(4) Regulation of water levels in Lake Okeechobee and canals leading oceanward from it. The St. Lucie and Caloosehatchee Canals form links in the cross-state waterway between Stuart and Fort Myers, on which the Corps of Engineers has responsibility for maintaining navigation. Attempt is made to hold lake levels between 12.6 and 15.6 feet above M.S.L. (U.S.C. and G.S. datum), a regulation made in the interest of supplying adequate water for transportation and, at the same time, maintaining lake level far enough below the levees so that they will not be overtopped by hurricane waves or surges. In ordinary times such control poses no difficult problems, but in times of drought or flood it is much more difficult, and is complicated by needs of water for agricultural purposes.

(5) Shortage of water for irrigation, municipal supplies, and other uses during droughts. Distribution of precipitation is not uniform either in place or time, and works for controlling flood excesses or drought deficiencies have not yet been adequately installed. When, and if, the Central and Southern Florida Flood Control District (Figure 1) program is completed, these needs will largely be taken care of.

(6) Overloading of main canals at times of heavy rainfall by many miles of new laterals. These hurry the water off lands distant from the main canals thus increasing the load the main canals are expected to carry.

(7) Flooding of human works and homes that inadvisedly or thoughtlessly have been built on river flood plains or other areas subject to flood during heavy rainstorms, such as the poorly drained flat lands adjacent to the Everglades or the coastal marshes, or the natural, high-level drainage ways such as the "transverse glades" (Harper, 1947, p. 176, and Parker *et al*, 1955, p. 144-146).

GROUND WATER

In order to keep this discourse as uncomplicated by technicel language and jargon as possible, we will avoid whenever we can the intricacies of geology. Formational names, ages, and stratigraphy will be replaced, wherever possible, by hydrologic units and concepts. There, too, will be kept as simple as is consistent with conveying true impressions.

Ground water in this region occurs either in shallow aquifers with a free upper water surface (having an air-water contact) or in artesian aquifers with a confined upper surface (Figure 2). The water surface of an unconfined aquifer is called the water table, whereas its counterpart in a confined (artesian) aquifer is a piezometric surface. Except in close proximity to a stream channel, wells tapping a water-table aquifer will not flow (and then only under certain circumstances). On the other hand, water levels in artesian wells always rise higher than the tops of the artesian aquifers they tap, and if topographic and structural features are favorable, as where the recharge area is high and the artesian head is

Fig. 1.—Index map showing report area.

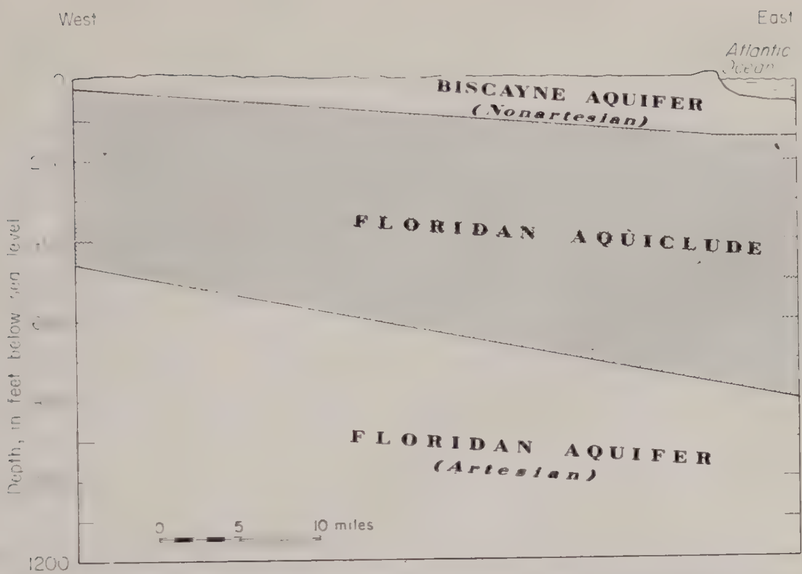

Fig.2.—Generalized cross section showing hydrologic units in the vicinity of Miami, Florida.

thus higher than adjacent lowlands, artesian wells will flow above the land surface in the lowlands.

In Florida all ground and surface water is dependent upon local precipitation as its source of origin. We cannot call upon mysterious underground rivers flowing from the Appalachian Mountains, as has been believed by some "old timers," nor can we count upon "new" waters spurting or seeping upward from magnetic sources deep within the bowels of the earth.

In a fairly well defined manner the researches of the U. S. Geological Survey and the Florida Geological Survey in cooperation with other agencies, have given us an understanding of the geologic framework within which the ground and surface waters occur. The U. S. Weather Bureau has also fairly defined the occurrence of water in its atmospheric phases, and research by the Geological Survey, the University of Florida Experiment Stations, and the Soil Conservation Service (lately, also, the Agricultural Research Service) have grossly determined the evapotranspiration losses from the land and water surfaces to the atmosphere. Thus we can now fairly accurately define the several phases of the hydrologic cycle in a quantitative manner. For southern Florida this was first done using water-budget methods by Langbein (Parker *et al*, 1955, p. 511-570) and for the lower Dade County area (Parker *et al*, 1955, p. 197-290). Results obtained will be discussed later in this paper.

Geologic factors become important the moment a raindrop strikes the land surface. Because of the geologic environment which exposes permeable materials over most of the area of the Central and Southern Florida Flood Control District, runoff is either greatly delayed or greatly reduced as compared with many other parts of the country. Over much of the area most of the rainfall either is absorbed quickly by the surficial materials and is subsequently discharged by ground-water seepage into

streams, canals, or the ocean, or returned directly to the atmosphere by evapotranspiration; over much of the era there is no surficial drainage.

Parker (Parker *et al*, 1955, p. 142) states that evapotranspiration probably accounts for the disposal of almost all the rainfall on the sandy flatland, even as it does in the Everglades. Clayton *et al* (1942, p. 27-35) have shown that for limited areas evapotranspiration may exceed rainfall with the deficiency being made up by seepage and or runoff from contiguous areas. Langbein (Parker *et al*, 1955, p. 512) summarized the annual hydrologic data for the 9,000 square miles of the southern Florida area reported upon (almost all included in the 15,570 sq. mi. of the Central and Southern Florida Flood Control District) and concluded that, for the interval of 1940-1946 (a fairly typical period) precipitation averaged 50.1 inches; there was a total measured runoff of only 7.5 inches; a water loss (approximately the evapotranspiration loss) of 42.6 inches; storage changes were essentially nil.

In his studies of Dade County ground-water conditions, Parker (Parker *et al*, 1955, p. 229-234) concluded that of the average annual rainfall of approximately 60 inches, about 38 inches reaches the water table (direct aquifer recharge) and about 22 inches is lost by evapotranspiration before ever reaching the water table. In this area (chiefly, the Atlantic Coastal Ridge) there is little or no direct runoff. Of the 38 inches that becomes ground-water recharge, discharge into the drainage canals and into the bays by direct seepage from the aquifer accounts for about 15 to 25 inches, more likely the higher value. The remainder, 13 to 23 inches, is lost by evapotranspiration directly from the water table or the capillary zone above it.

WATER-TABLE AQUIFERS

Almost everywhere in Southern Florida water-table aquifers of greater or lesser utility exist. Where these aquifers are sandy or composed of limestone, they make excellent sources of water, providing that they are not contaminated with or threatened by salt water encroachment. Where composed of dense and less permeable materials such aquifers provide low yields and often carry water of poor quality.

Biscayne Aquifer

Underlying the greater part of Dade County, most of Broward County and part of eastern Monroe and southern Palm Beach County is one of the most prolific aquifers ever investigated by the U. S. Geological Survey. This is the famous Biscayne aquifer described by Parker, 1951; Parker *et al*, 1955, p. 160-162; Schroeder *et al*, 1958; and Kohout, 1960. This aquifer is at once one of the area's greatest natural resources and one of its most difficult assets to protect. It is the only source of fresh water in Dade and Broward Counties.

The wedge-shaped Biscayne aquifer, 100 to 200 feet thick in the east and thinning to a few feet in the western Everglades, is shielded only along its base where it rests on a gently sloping impermeable floor of clay, silt and dense marl. No saline intrusion can work its way upward through these materials (part of the Floridan aquiclude, which is the cover of the underlying Floridan aquifer; these will be discussed later). But the Biscayne aquifer is leaky above and on all sides. Rain finds ready access

to this aquifer and with Miami's 60 inches of rainfall keeps the aquifer nearly full much of the time. The aquifer is open to the ocean on its seaward side and here, in an island sloping contact zone some 60 to 80 feet in thickness, the fresh water of the aquifer makes contact with, and discharges into, salty bay and ocean water (Kohout, 1960).

In man's attempts to drain the Everglades he has cut through the upper part of the Biscayne aquifer, bleeding off its topmost reserves of high quality ground water, and in doing so, has created arms of the sea (the drainage canals) which, if not controlled, would largely ruin the fresh water supply of this entire eastern part of Dade and Broward Counties (Parker, 1951; Stallman, 1956; and Schroeder *et al*, 1958).

Tremendous quantities of water are stored in the Biscayne aquifer. However, most of this is "dead storage"—water that generally lies below sea level and therefore cannot be drawn out without danger of its replacement by ocean water. Fortunately, this area's normally copious rainfall of 60 inches per year, which supplies on each square mile of this area more than one billion gallons of water, offers a potential supply that few areas in this country can match. Of course, not all of this billion-plus gallons becomes recharge. Parker's estimate of 38 inches of recharge, (Parker et al, 1955, p. 229-234) for the coastal ridge south of Miami indicates there is an average annual supply of new water on each square mile of about 0.7 billion gallons. Even after losses due to evaporation directly from the water table, this still leaves an average annual net gain of about 0.15 to 0.45 billion gallons a year on each square mile. It is this "new" water, plus the carry-over in storage from previous years' rainfall, that we must manage for our use and protection.

The biggest difficulty in this management stems from the small thickness of aquifer available for storage above sea level. An idea can be gained of this limitation when we realize that highest to lowest ranges in average monthly water-table stages in the upper Everglades area is about 7 to 7.5 feet, and along the coastal ridge such ranges are about 4.5 to 8.5 feet. These translate into quantities over a square mile for each area as follows, allowing for an effective storage factor in the Biscayne aquifer of 0.20:

STORAGE CHANGES, IN BILLIONS OF GALLONS PER SQUARE MILE HIGHEST TO LOWEST AVERAGE MONTHLY WATER-TABLE STAGES

Upper Everglades Area		Coastal Ridge Area	
Range in stage	Change in storage	Range in stage	Change in storage
7′	0.29 b.g./sq. mi.	4.5′	0.19 b.g./sq. mi.
7.5′	0.31 b.g./sq. mi.	8.5′	0.36 b.g./sq. mi.

Highest water-table stage of record occurred in October 1947, following the second of two closely spaced hurricanes (Sept. 17 and Oct. 11). Lowest levels of record occurred in June 1945, following two years of deficient rainfall during which only about one year's normal rainfall occurred. Both events were of disastrous consequence and were largely responsible for the eventual establishment of the Central and Southern Florida Flood Control District.

Other Shallow Aquifers

In this category are placed all aquifers, other than the Biscayne, that lie above the Floridan aquifer. These are generally sand, sand and shell,

or marl and limestone deposits of relatively limited extent. Except for the Biscayne aquifer, none have been described as distinct, named, hydrologic units, although with considerable detailed work this might be done.

COASTAL RIDGE AREA

Along the Coastal Ridge north of the Biscayne aquifer where it peters out in southern Palm Beach County and northwestern Broward County, is an extensive linear aquifer strip between the Everglades on the west and the ocean on the east as far north as Stuart. Farther north it is bounded on the west for most of its length by the St. Johns River valley. Comprised chiefly of sand, shells, and marl with lesser amounts of limestone, and coquina, this more or less continues and permeable strip is the chief source of fresh-water supply throughout an area aboue 230 miles long and averaging a few miles wide.

The upper surface of the Atlantic Coastal Ridge marks the upper limits of the shallow aquifers. In some places, atop ancient dunes and beach ridges, this is 50 or more feet above sea level. The thickness of the aquifers ranges from more than 200 feet in the south and east to a feather edge in the west. They are generally thinner to the north in Indian River and Brevard Counties than to the south. Brown *et al* (1957, p. 2-3) report the average thickness of the aquifer in Brevard County to be about 50 feet but it is less than 20 feet thick in the vicinity of the St. Johns River Valley. Bermes (1958, p. 19) reports that in Indian River County the aquifer is thickest along the crest of the coastal ridge and on the barrier beach, but that at the Adrianna Ranch, in the St. Johns Marsh, it is not more than three feet thick.

The aquifers vary in width, depth, and permeability from place to place, depending upon their internal composition and topographic expression. Generally they are sandy in the upper parts and in places are separated from its lower permeable parts by one or more layers or lenses of marl. Thus, a shallow unconfined aquifer exists at top, and in places from top to bottom, and one or more low-pressure artesian aquifers may exist below. The marl layers (aquicludes) in some areas are quite extensive and project seaward beneath the saline water of the coastal lagoons and ocean. In such situations the aquicludes act as caps to underlying shallow artesian zones and prevent or deter the encroachment of salt water into the artesian zones. Typical of such conditions are areas at Fort Pierce (Parker *et al*, 1955, p. 176, 194-195); at Stuart (Lichtler, 1957); and Vero Beach (Bermes, 1958, p. 19).

Salt water underlies the coastal ridge aquifers in some areas and is everywhere present along its eastern boundary. With careful development of wells, fairly large water supplies could be developed in most parts of the aquifer along or near the coast line. In some areas, however, such as in central Brevard County, saline water is present even at shallow depths in the aquifer (Parker, 1946, p. 77-78) and this, combined with low permeability, makes for difficult water-supply developments.

Drainage of the Everglades and St. Johns Marshes, or of other coastal areas, has to date had little noticeable effect on the ground water in the shallow aquifers in the Cosatal Ridge area. This is in stark contrast to the coastal aquifer in Dade and southern Broward Counties. In the area of the coastal ridge aquifers there has been maintained a higher water table, through a system of carefully operated water-level controls, than

has been the case in Dade and southern Broward Counties. Additionally, the geologic materials of the coastal ridge aquifers are generally of much lower permeability than those of the Biscayne aquifer. Thus, salt-water encroachment would not be as rapid in taking place, even if the water table were lowered enough to induce it.

Salt-water encroachment in the aquifers is not now of major importance as it is in the Biscayne aquifer. For example, wells 100 feet deep near the shoreline of Lake Worth (a salt-water lagoon) can still obtain fresh water just as similar wells once did in the Miami-Fort Lauderdale area prior to drainage. Other places, as at Fort Pierce well field area, have experienced encroachment problems. With passing time, enlarging population, and greater ground-water withdrawals from these aquifers salt-water encroachment problems may become very serious, especially in those areas where overpumping is allowed to develop.

In connection with future development it may be valuable to gain an idea of qualities involved in recharge to and discharge from the area underlain by the shallow aquifers in the Coastal Ridge area. Storage in the aquifers, of course, fluctuates seasonably, but quantities are not now measured. When, after a dry spell a hard rain occurs, much of the rainfall is available for recharge. On the other hand, if such a rain occurs following a period of wet weather, the aquifers may be full to overflowing. At such a time all or most of the subsequent rainfall is rejected because the aquifers have no place in which to store the new supply., Obviously the most effective recharge occurs during dry periods.

Data used herein are not "spot" data for any particular observation station. Instead they are chosen to represent conditions over a fairly large area. Precipitation is given in whole inches and recharge or discharge in millions of gallons per square mile (mgsm). Precipitation and evapotranspiration data are from Parker (Parker *et al*, 1955, p. 22-40, 22-235). Data have been chosen to represent average conditions. The areas considered are northern (near Titusville), central (near Fort Pierce), and southern (near Boca Raton).

Of the data utilized, the precipitation records are considered excellent. Evapotranspiration losses, however, are not so good, and may not be applied at present for short periods, as a year or less. Most applicable, perhaps, for averages over a period of years are the estimates made by Parker (Parker *et al*, 1955, p. 229) for losses from the Biscayne aquifer along the coastal ridge in south Dade County. Parker found evapotranspiration losses there to be about 35 inches a year. Smith (1956, p. 22) reporting for agricultural lands where the water table was within 2 feet of the land surface, reports evapotranspiration losses ranging from about 40 to 50 inches a year. This compares with the loss of 60 inches a year for Everglade soils covered with sawgrass and having a water table averaging 2 feet below the land surface (Clayton *et al*, 1942, p. 35). The Everglades conditions are not the same as those of the Atlantic Coastal Ridge, but for its lower lying parts the range in water losses is believed to be of about the right order of magnitude.

For estimating average conditions along the Coastal Ridge, a value of 35 inches has been used for evapotranspiration loss. In some years this loss may be 10 or more inches different, plus or minus; thus, a range may exist between 25 inches and 45 inches. It is fully recognized that these figures may be considerably in error. However, for our purposes in esti-

mating amount of gains and losses over the area underlain by the aquifers, these will do until basic data are better defined.

The following tabulation summarizes estimated conditions in representative parts of the area underlain by the shallow aquifers for an average year.

ESTIMATED POTENTIAL GAINS TO AND LOSSES FROM THE SHALLOW AQUIFERS IN THE COASTAL RIDGE AREA.

	Northern part	Central part	Southern part
Average annual precipitation	52 in.	55 in.	60 in.
Average annual evapotranspiration	35 in.	35 in.	35 in.
Average annual potential gain	17 in.	20 in.	25 in.
Potential storage gain (mgsm)	295.3	347.4	434.2

Thus, in an average year, the aquifers in the northern part of the area stand to gain about 295 million gallons of water over each square mile of its surface. This is at an average recharge rate of about 809,000 gallons a day which is enough (if only half of it were captured) to supply, at 150 gpcd (gallons per capita daily), the needs of about 2,700 persons and not draw on previous storage at all. Thus, at this rate, an area of 10 sq. mi. would supply a town of about 27,000 people.

In the central part the aquifers receive an average annual potential recharge of about 347 million gallons a square mile. If only half of this were captured, it would supply at 150 gpcd about 3,100 persons and a 10 square mile area would thus suppcrt a town of about 31,000 persons.

In the southern part the aquifers receive about 134 million gallons of potential recharge a year per square mile. If half this were captured and used at 150 gpcd, it would suffice for about 4,000 persons, or from a 10 square mile area enough water could be obtained to supply a city of about 40,000 persons.

UPPER ST. JOHNS RIVER VALLEY AREA

In addition to underlying part of the aquifers in the Coastal Ridge area, salt water underlies the Upper St. Johns valley. Southern Florida was flooded in latest ice-age time by salty ocean water, even as the Bay of Florida now floods that low-lying area. The latest ice-age strand line (Wisconsin time) was then (about 10,000 or more years ago) about 25 feet above present sea level, and only the highest parts of the present Coastal ridge stood above the ocean as a string of islands or bars, much as in the Cape Canaveral area today. At that time the entire St. Johns valley was a salt-water sound, an inland arm of the ocean.

Following this high level stand of the ocean the sea level fell 25 feet or so, about to its modern level. Then, during the Climatic Optimum (Brooks, 1949, p. 364) which began about 5,000 years before, present sea level rose to about 5 to 8 feet and remained there long enough to carve the wave-planed Silver Bluff terrace (Parker *et al*, 1955, p. 125; see also pl. 13 and fig. 23). Salty ocean water then occupied much of the present Everglades-Lake Okeechobee depression and extended far up the St. Johns valley. About 3,000 or so years ago the ocean assumed its approximate present level.

Thus, during these two higher level stands of the sea, the underlying rocks became saturated with salt water, and not enough time has elapsed since it got in for the salt water all to be flushed out. In the more permeable formations of southern Florida this ice age sea water has been flushed out, but in less permeable parts, and at greater distances from the ocean, bodies or pockets of salty water still persist. Much of the Upper Everglades and the Lake Okeechobee basin is underlain by salty water at very shallow depths, even as are parts of the Atlantic Coastal Ridge and the St. Johns River valley (Stringfield, 1936; Parker *et al*, 1955, p. 821-822).

The presence of this salty water in the Upper St. Johns valley gives rise to problems in connection with the plans of the Central and Southern Florida Flood Control District and the Corps of Engineers for flood-control and drainage works. Perhaps it would be well to discuss this briefly.

Underlying the Upper St. Johns area at relatively shallow depths is the Floridan aquifer, which is the principal artesian aquifer of the state. Its confining beds are quite leaky here, its piezometric surface (height to which water in tightly cased well will rise) ranges, at Puzzle Lake, about 7 to 11 feet above M.S.L. in a narrow strip along the river. Thus, salty ice-age ground water leaks upward to the river channel and contaminates the river, the lakes and marshes, and the shallow water-table aquifer.

In its upper reaches, as at Lake Hellen Blazes and southward, water in the St. Johns River has a chloride content of about 20 ppm (parts per million), which is normal for uncontaminated water in this region. However, 50 or so miles downstream, at Puzzle Lake, the chloride content rises at times to 1,000 ppm.

The District plan is to place a water-control structure on the S. Johns River just above the juncture with the Econlockhatchee River, near Florida State Highway 46. Water levels in the Puzzle Lake Reservoir would be held at stages between 6 and 10 feet M.S.L. According to A. O. Patterson (written communication, 1960), the unregulated stage of the St. Johns River in the Puzzle Lake Area is less than 2 feet above M.S.L. 50 percent of the time; and during extreme droughts the stage drops to about 0.5 foot below M.S.L., whereas in floods it rises as high as 10.5 feet above M.S.L.

Accordingly, most of the time there exists a difference in head between the stage of the river and that of the Floridan aquifer amounting to about 7 feet. It is this upward hydraulic force that moves salty, ice-age, artesian water into the river channel and the adjacent shallow aquifer.

Operation of the proposed plan would reduce this head differential to, perhaps, an average of about one foot, thus reducing the flow of saline water into both the river and the aquifer adjacent thereto. Just how great this reduction would be cannot now be determined because sufficient data are not available. Further, by maintaining more nearly uniform pressures in the valley, the chemical quality of the water in the St. Johns River would be much more constant than it now is. For example, under natural conditions at the Christmas gauging station of the U. S. Geological Survey at Florida Highway 50, chloride concentration drops as low as about 30 ppm during high-water stages but rises as high as almost 600 ppm during low-water stages.

One other feature of the plan as it may effect the water quality of the Upper St. Johns valley should be noted in passing. Should the Sebastian

canal be dredged and operated as planned it would drain off to the Indian River the freshest water of the valley—water that if not drained eastward would be available to dilute the salty water further downstream.

THE EVERGLADES AREA

Little new has been learned of the occurrence of water in the rocks of the Everglades lying above the relatively impermeable clay, silt, and marl of the Floridan aquiclude since Parker's report of 1955 (Parker *et al.* 1955, p. 178-185). Details of the western part of the Biscayne aquifer have been filled in (Schroeder *et al.* 1958) but these do not change earlier major conclusions about the aquifer or the water supply.

The emplacement of Central and Southern Florida Flood Control District works, as a permanent addition to, or substitution for some of the existing control structures, is bound to be a boon to the area. Water levels can be held somewhat above uncontrolled levels, and except for opposition of land-owners whose properties would be in some extent damaged by higher levels, might be held considerably higher. The higher water levels, maintained by controls as near Biscayne Bay as possible, not only help to maintain a high enough head of fresh water in the Coastal area to hold salt water encroachment in check but they make a great deal more water available for municipal use and for irrigation: additionally, where levels are held higher in the Everglades they help prevent muck fires, materially decrease the oxidation of the organic peat and muck, and are a godsend to fish and wildlife.

In the central and upper Everglades the new project works are already making it possible to control water with an effectiveness once believed almost impossible to reach. The dike along the eastern margin of the area has already saved much flood damage from occurring along the populous Costal Ridge, which lies to the east, and as more of the works are completed operations should become even more effective in these respects.

The aquifiers of the middle and upper Everglades are, for the most part, shallow and largely filled with salty ice-age water. Some areas are underlain by permeable limestone reefs or "shoestring" sands, and where these connect with Lake Okeechobee or are cut by canals connecting with the lake, fairly large, permanent supplies of fresh water are available.

The quality of the water in the shallow Everglades aquifers becomes progressively worse northward toward Lake Okeechobee (Parker *et al.* 1955, p. 818-822) and under the lake bottom the poorest quality of water in the area occurs. The conditions have been reported in considerable detail by Parker (1942, p. 47-76) and Parker and Hoy (1943, p. 33-55 and 77-94).

Ground water is practically stagnant underneath the lake, and even ground-water discharge into the lake from surrounding higher lands is negligible, despite a long-standing local belief that the lake is chiefly fed by springs and seeps from underground flow ("underground streams") originating on the highlands to the north. Wallace tentatively concluded (Cross *et al*, 1940) as a result of water-budget analysis of Lake Okeechobee, that there could be neither a substantial gain by ground-water flow into, nor loss by ground-water flow out of, the lake. Later, Parker *et al*, 1955, p. 107) verified these conclusions from ground-water data. He concluded that there is an average inflow into the lake from the 10-foot thick

aquifer that connects with the lake on its western, northern, and eastern sides amounting to only about 730 acre feet a year, or about 1.1 cfs per day.

It is concluded that while the project works in the Central and Southern Florida Flood Control District will have a very important effect on surface water and especially on flood control operations in the area they can have little effect in changing ground-water conditions in the Everglades area.

THE KISSIMMEE RIVER VALLEY AREA

The hallow sand and marl deposits in the Kissimmee Valley area that lie above the artesian and their covering aquicludes are almost always full to overflowing. Permeability of the detrital materials that comprise the shallow aquifer is low, perhaps ranging from about 800 to 10 gallons per day per square foot of cross-sectional area of the aquifer, at 60°F, under a hydraulic gradiant of 100 percent (this compares with 50,000 to 25,000 in the Miami area). Thus, the shallow aquifer neither has a great deal of storage in it nor is water transmitted very rapidly through it, under the gradients that exist in nature.

The deeper artesian aquifers here, as everywhere else in southern Florida (except in the Upper St. Johns Valley as mentioned earlier), are insulated from the overlying surface waters, thus conditions in the overlying shallow aquifer, or in the surface bodies of water, have no effects whatever on the artesian aquifer.

Only to the extent that District control works provide more effective drainage will the ground water of the shallow aquifer in the Kissimmee Valley area be much affected. This will result in providing storage space in the shallow aquifer for heavy rains, thus to some extent reducing flooding. The quality of the water, except for its dark color and erratic distributions of iron, is everywhere good to excellent. Central and Southern Florida Flood Control District operations should have a minor effect on ground water in the valley.

THE CALOOSAHATCHEE RIVER VALLEY AREA

In the area above Fort Myers the information on the ground-water situation, especially in the shallow aquifer, is scarce and spotty indeed. Detailed ground-water studies were conducted by the U. S. Geological Survey in the Fort Myers area during World War II, and a memorandum report was prepared for use of the City of Fort Myers. However, no published report of that area has ever been prepared.

Beginning in 1945 and concluding in 1947, the Soil Conservation Service (1948) undertook a study of the land capabilities of the Caloosahatchee River valley. As a part of these studies several lines of shallow water-table observation wells were installed in the valley. These, together with several maintained in the Fort Myers and Big Cypress Swamp areas by the U. S. Geological Survey, constitute the best data available for evaluation of the shallow ground water supply.

Smith (1955, p. 12-17) has summarized these data and other related information and drawn therefrom these important conclusions:

(1) Best and most useful ground water occurs in the shallow, water-table aquifer.

(2) The aquifer is kept near full to overflowing most of the time by adequate rainfall.

(3) Water levels fluctuate a few feet seasonably, and show greatest fluctuations near the Caloosahatchee river and canal. This is because of fairly highly permeable shell and sand layers in the Fort Thompson formation and in underlying Caloosahatchee formation.

(4) Quality of this ground water is suitable for most purposes and is far superior to that from the deep-lying Floridan aquifer, the water of which has killed citrus trees when used for irrigation purposes during very dry weather.

(5) The Floridan aquifer is completely isolated from any surface bodies of water in this region and neither receives nor loses water (except through artesian well discharge). It has a piezometric head of about 40 to 50 feet above M.S.L. in the Caloosahatchee River valley area, thus if any leakage were to occur it would be upward as a consequence of the hydraulic head.

(6) Protection of the shallow ground-water supply from overdrainage and from salt-water encroachment are highly desirable objectives. The former is chiefly a function of individual landowners but the latter can be achieved by construction of a control works in the Caloosahatchee River as far downstream as feasible. Smith (1955, p. 17) suggests that a lock and dam should be implaced at least as far downstream as Olga.

THE ARTESIAN AQUIFERS

Although there are several shallow, low-pressure, and highly valued (locally) artesian aquifers in southern Florida, none of these are widespread or have relatively unlimited supplies. Of these shallow artesian aquifers within the Central and Southern Florida Flood Control District area, the most useful are those that underlie the shallow coastal ridge aquifers in some places. Insulated from overlying salty water of the ocean or connecting salt-water lagoons, these shallow artesian aquifers are the only source of usable fresh water for coastal or barrier reef supplies.

The Floridan Aquifer

Underlying the entire area covered by this report is the Floridan aquifer, one of the greatest of the world's aquifers. In southern Florida it is deeply buried, being about 900 feet below sea level at Miami and 800 feet at Everglades City; in northwestern Brevard County it is about 75 feet below sea level and in its northeastern corner about 300 feet deep. Overlying the aquifer, and completing it as an artesian system, is the thick wedge-shaped series of relatively impermeable clay, silt, marl, and fine sand that has been called the Floridan aquiclude. (Parker *et al*, 1955, p. 189).

The piezometric surface of the Floridan aquifer in 1944 is shown by Parker *et al* (1955, p. 190) in a map compiled by V. T. Stringfield, H. H. Cooper, Jr., and M. A. Warren of the U. S. Geological Survey. The high domed area in Polk County is the principal source of recharge to the aquifer in southern Florida. Flow of water is radially outward in all directions from this high, where water levels stand at more than 130 feet above sea level. Except for seasonal fluctuations, the piezometric surface in southern Florida has not changed notably since it was first mapped (Stringfield, 1936).

Over most of the area of the Central and Southern Florida Flood

Control District water in tightly cased wells penetrating the Floridan aquifer will rise to heights of 40 to 60 feet above M.S.L. (mean sea level, U. S. Coast and Geodetic Survey 1929 datum). This is an advantage that farmers, industrialists, engineers, and others would like to utilize. However, the salinity and corrosiveness of the water, and the much greater cost of obtaining it (as compared with use of water from shallow aquifers), have greatly limited its use.

Except for the leakage of salty Floridan aquifer water upwards in the upper St. Johns valley, as previously discussed, the writer can see no reason to expect that the planned project works for the Central and Southern Florida Flood Control District will in any way affect the Floridan aquifer or its water. In the upper St. Johns valley, the installation of dams in the river might reduce salinity and stabilize at a much lower level the salt content of the river, the reservoirs, and the adjacent shallow aquifer.

SALT-WATER ENCROACHMENT

Probably more has been written on this subject than on any other phase of the water situation in southern Florida, and the situation is too well known to require the full treatment here.

In general, it may be said that salt-water encroachment still remains the principal threat to the safety of coastal water supplies in this region. However, the only place where salt water continues actively to threaten the supply is in the Biscayne aquifer from the Oakland Park area, north of Fort Lauderdale, to and beyond Florida City.

North of Oakland Park, according to Sherwood (1959, p. 26-29) salt-water encroachment has been limited to areas close to the Intracoastal Waterway or Cypress Creek. This limitation is partially due to the high ground-water levels maintained by the control near the mouth of Pompano Canal and to the fact that Cypress Creek is not an improved drainage channel such as Middle River and the South Fork of New River, in and along which encroachment continues. In the New River basin salt water has migrated inland, at depth in the Biscayne aquifer, as much as 3½ miles from the coast. Near the South New River Canal, at a point 5½ miles from the coast, samples from wells collected periodically since 1941 indicate large and rapid changes in chloride content of the ground water caused by variations in the amount of salt water in the New River.

According to Schroeder *et al* (1958, p. 42), salt water has not yet encroached as far inland as U. S. Highway No. 1 between Dania and Hollywood, a distance of about 1½ miles from the coast. Nor has salt water yet encroached into the Fort Lauderdale southern well field, about 6 miles from the coast. Vorhis (1948) indicated that salt water underlies the well-field area at a depth of about 200 feet. He pointed out that encroachment into the Fort Lauderdale field may be from any of 4 sources: (1) ocean water at depth in the Biscayne aquifer; (2) ocean-water tongues in the drainage canals; (3) brackish water from ice-age residual bodies in the Everglades transported in the canals during drought flow; and (4) vertical rise of the ice-age residual sea water from beneath the well field.

The construction in 1959 of a network of canals draining to the North

New River Canal west of the Fort Lauderdale field may contribute to the danger of lateral intrusion from the river during long drought periods.

Of course, the most serious salt-water condition is in the Dade County area. Parker's map of the Dade County encroachment zone (Parker *et al.* 1955, p. 709) shows the situation in 1946, as does Klein's map of the same subject for 1951. In this 5-year interval several important changes took place. In the North Miami area, between Arch Creek and Biscayne Canal, a notable island advance of the salt front occurred; likewise an advance of significant proportions took place in Miami Shores between Biscayne and Little River Canals. Little change occurred between Little River and Miami Canals, but the tongue of salty water following along Tamiami Canal pushed ahead to Red Road and broadened out to the northwest between the Tamiami and Miami Canals. In Miami proper little change is apparent but in Coral Gables in the area between Sunset Drive and Snapper Creek Canal a wide advance of salt-water encroachment took place. South to the Florida City Canal only a slight westward encroachment occurred, but in the low coastal marshes to the southwest, south, and southwest of Florida City an appreciable advance was made. Large changes in the position of the salt front may occur from year to year in these low-lying areas. During dry seasons water levels in the coastal marshes frequently approach sea-level elevations and at times decline to elevations below sea level. Such decline permit the salt front to move inland toward the ridge. When rains occur and water levels rise, the front retreats. In 1960, after 3 years of above-normal rainfall, the salt front was more than 5 miles south of Florida City.

No map for the salt-water encroachment zone of Dade County is available to compare 1960 conditions with those of 1951; however, it is believed that no great additional changes have occurred except in the North Miami, Tamiami-Miami Canal, Coral Gables, and coastal marshes areas, as will be explained later.

Details of the encroachment pattern for the Miami area are best shown on the series of 5 maps developed by Parker (Parker *et al.* 1955, p. 589, fig. 169), and the additional map added by Klein (1957, p. 3, fig. 1). Since then Kohout (1960, in press) has worked up an additional map for 1959. In all, these 7 maps portray changes in the encroachment pattern in the Biscayne aquifer of the Miami area for 1904, 1918, 1943, 1946, 1950, and 1959—a span of 56 years of record.

These maps show the pattern of encroachment as it took place at depth in the Biscayne aquifer and by way of the tidal canals. They show that the major spread of the encroaching salt-water wedge took place beween 1943 and 1946, a period of major drought, low water levels, low flows in the canals, and no hindrance to salt-water movement up the canals (until 1945). In the Silver Bluff area of Miami the wedge had moved inland at an apparent rate of about 225 feet a year until 1943, then in a 27-month period that overlapped 1943 and 1944 it advanced 2,000 feet inland, a rate of about 890 feet a year.

With the emplacement of controls in Miami, Little River, and Biscayne Canals a seaward retreat of the salt-water tongues along those canals took place. Dams were also placed in the Coral Gables and the Tamiami Canals. However, these were so far inland that they had little if any effect in counteracting the spread of saline encroachment. As a result the wedge continued to move inland in those two areas.

Principal changes shown on the 1953 and 1959 maps of this series are along the Tamiami Canal and in the intercanal area between Biscayne Canal and Arch Creek. These are areas in which the acquifer has not been adequately protected by downstream salt-water controls.

In the Tamiami Canal area, lying east of Red Road and between the Tamiami and Miami Canals, the salt-water wedge moved about ½ mile west along the Tamiami Canal between 1950 and 1951 to reach Red Road. Since then the forward edge of this salt-water tongue has held at Red Road but the front between Tamiami and Miami Canals has moved northwest about ¾ of a mile and is now scarcely 1¼ miles southwest of the Hialeah well field. There will always be concern for the safety of the Hialeah well field until such time that the control is moved downstream to a location where both the Miami and Tamiami Canals can be adequately controlled.

Whether to save the Hialeah well field, or to abondon it and move to a site in the Everglades several miles to the west, is a matter of concern to taxpayer and officials of Miami, Dade County, and the Central and Southern Florida Flood Control District. The Survey's job in this instance is to keep a close survelliance of the hydrologic conditions and make the facts available to the public and the public servants so that upon due consideration of the facts local decisions and actions can be made as seem required.

The other area of serious encroachment is inland between Arch Creek and the southwest reach of Biscayne Canal. In this area the salt-water wedge has started moving inland most rapidly since 1953 and by now has contaminated several wells in the North Miami field. The salt wedge has penetrated at a point midway between Arch Creek and Biscayne Canal, about 1¾ miles in from Biscayne Bay; in 1953 it was about 1¼ miles; in 1950 about the same; in 1946 about ¾ miles; in 1943 about ¼ mile; and prior to that it was about at the shoreline. Thus, in this area, the front has moved inland, in 16 years (1943 to 1959 inclusive) about 1½ miles, or a rate of about 500 feet a year. Clearly, if the salt-water encroachment in this area is to be contained, some effective downstream controls are going to be required.

SUMMARY

In the Central and Southern Florida Flood Control District the artesian aquifers generally are deeply buried and not in hydraulic connection with streams or other surface water bodies of the valleys or lowlands. Thus they will be unaffected by surface water controls that may be built and operated in the District. To this generalization one important exception occurs, and that is in the upper St. Johns River valley. There, from about Lake Hellen Blazes to Puzzle Lake salty water seeps upward from the shallowly buried Floridan aquifer and raises salinity in the river from about 20 ppm to 1,000 ppm in a stretch of about 50 miles. Plans of the Central and Southern Florida Flood Control District are to place dams in this stretch of the river, thus raising water level in reservoirs. This would create a fresh-water head above sea level sufficient to greatly retard upward leakage, and thus saline contamination, from the Floridan aquifer. Also, the more constant head maintained would likely level out the salinity of the river and reservoirs considerably.

Ground-water conditions in the Coastal Ridge aquifers are discussed. The aquifers in an area about 230 miles long and a few miles wide stretch from Palm Beach to St. Johns County. Generally quite sandy and shelly, they have some rather impermeable marly layers of considerable areal extent in their lower parts, thus ground water beneath these layers is confined and low-pressure artesian aquifers are created. Locally these are of great importance near the shore because fresh water can be obtained in them beneath salt water that occupies overlying permeable parts of the aquifers.

The shallow aquifers in the Coastal Ridge area are thickest in Palm Beach County where they may be over 200 feet thick. They thin gradually to the north and west. In Brevard County they are about 50 feet thick under the crest of the coastal ridge and but a few feet thick in St. John's valley. Differences between recharge and discharge in an average year are such that, in the northern part of the area there is a net gain of about 295 million gallons of water a year over each square mile of aquifer surface, in the central part of about 347 million gallons, and in the southern part of about 434 million gallons. This is sufficient water, from one square mile, at 150 gallons per person per day to satisfy the needs of 4,400 persons in the northern, 6,300 persons in the central, and 7,900 person in the southern parts. If only half the recharge were captured, the population served, as listed above, would be halved.

In extremely wet years the shallow coastal ridge aquifers cannot hold all the rainfall that is available, but in extremely dry years, they may lose more water through evapotranspiration alone than they receive. However, over most of the area, there is ample water in storage to carry over until an ensuing wet year refills the aquifers. To date salt-water encroachment has not been a serious problem, except in localized instances, in these aquifers. Salt water occurs, however, underneath the aquifers in some areas; also, as near Cocoa, saline water occurs in it even at shallow depths and it is very difficult in such areas to develop adequate fresh ground-water supplies.

No serious ground-water problems are foreseen anywhere else in the District either as a result of Central and Southern Florida Flood Control District operations, or from other causes, except in the eastern segment of the Biscayne aquifer from about Oakland Park, in southern Broward County to Florida City in southern Dade County. In this coastal strip salt-water encroachment continues to be the chief threat to the safety of the water supply. In parts of the area, as at Silver Bluff and Cutler, the encroaching salt-water wedge appears to be stabilized. In other areas, as in North Miami; the area between Red Road, the Tamiami Canal and the Miami Canal; the Coral Gables area; and the coastal marshes near Florida City, encroachment continues inland. Such encroachment can be controlled, if it seems desirable to do so, by the emplacement of low-level, low-head dams in the drainage canals as far downstream as feasible.

The U. S. Geological Survey does not advocate any course of action to control or prevent salt-water encroachment, for this is in the province of the local people and the action agencies. The survey's job is to keep the situation under surveillance and make the facts available to the public and to the public servants so that upon due consideraion of these facts local decisions and actions may be made as seem required.

LITERATURE CITED

1. Bermes, Boris, J. Interim report on geology and ground-water resources of Indian River County, Florida. Florida Geol. Survey Info. Circ. No. 18. 1958.
2. Brooks, C. E. P. Climate through the ages. McGraw-Hill Co., New York. 1959.
3. Brown, Delbert W., W. E. Kenner, and Eugene Brown. Interim report on the water resources of Brevard County, Florida. Florida Geol. Survey Info. Circ. No. 11. 1957.
4. Brown, R. H. and Garald G. Parker. Salt-water encroachment in limestone at Silver Bluff, Miami, Florida. Econ. Geol. Vol. 4, No. 4. 1945.
5. Clayton, B. S., J. R. Neller and R. V. Allison. Water control in the peat and muck soils of the Florida Everglades. Florida Agric. Exp. Sta., Bul. 378. 1942.
6. Cross, W. P., S. K. Love, Garald G. Parker, and D. C. Wallace. Progress report on the investigation of water resources in southeastern Florida. U. S. Geological Survey Mimeo. Rep., Washington, D. C. 1940.
7. Evans, C. B. and R. V. Allison. The soils of the Everglades in relation to reclamation and conservation operations. Soil Sci. Soc. of Florida Proc., Vol. 4-A. 1942.
8. Harper, R. M. Natural resources of southern Florida. Florida Geol. Survey 18th Ann. Report. 1927.
9. Jones, L. A. Soils, geology, and water control in the Everglades region. Univ. of Florida Agric. Exp. Sta. in cooperation with U. S. Soil Conserv. Service Bul. 442. 1948.
10. Klein, Howard. Salt-water encroachment in Dade County, Florida. Florida Geol. Surv. Info. Circ. No. 9. 1957.
11. Kohout, Francis A. Cyclic flow of salt water in the Biscayne aquifer of southeastern Florida. Jour. of Geophysical Research, Vol. 65, No. 7, July. 1960.
12. Lichtler, W. F. Ground water resources of the Stuart area, Martin County, Florida. Florida Geol. Survey Info. Circ. No. 12. 1957.
13. Marmer, H. A. Tide observations at Baltimore and the problem of coastal stability. Geogr. Rev., Vol. 33. 1941.
14. Marmer, H. A. Sea-level changes along the coast of the United States in recent years. Am. Geophys. Union Trans., Vol. 30, p. 201-204. 1949.
15. O'Reilly, John. South Florida's amazing Everglades. Nat. Geog. Mag., Vol. 77, No. 1. 1940.
16. Parker, Garald G. Notes on the geology and ground water of the Everglades in southern Florida. Soil Sci. Soc. of Florida, Vol. IV-A, p. 47-76. 1942.
17. Parker, Garald G., Municipal water-supply problems of southern Florida. Soil Sci. Soc. of Florida, Vol. 8, p. 72-88. 1946.
18. Parker, Garald G. Geologic and hydrologic factors in the perennial yield of the Biscayne aquifer: Am. Water Works Assn. Jour., Vol. 43, No. 10, Oct., p. 817-834. 1951.
19. Parker, Garald G. The encroachment of salt-water into fresh: *in* Yearbook of Agriculture, 1955. Dept. of Agric., Washington, D. C., p. 615-35; 723. 1955.
20. Parker, Garald G. and Nevin D. Hoy. Additional notes on the geology and ground water of southern Florida. Soil Sci. Soc. of Florida, Vol. V-A, p. 33-55 and 77-94. 1943.
21. Parker, Garald G., G. E. Ferguson, H. K. Love, and others. Water resources of southern Florida: U. S. Geol. Survey Water-Supply Paper 1255. 1955.
22. Schroeder, M. C., Howard Klein, and N. D. Hoy. Biscayne aquifer of Dade and Broward Counties, Florida: Florida Geol. Survey Rept. of Inv. No. 17. 1958.
23. Sherwood, C. B. Ground-water resources of the Oakland Park area of eastern Broward County, Florida. Florida Geol. Survey Rept. of Inv. No. 20. 1959.
24. Smith, David B. Florida's water resources, a report to the Governor of Florida and the 1957 legislature. Florida Water Res. Study Com., Gainesville, Florida, Dec. 1956.
25. Smith, David B. A study of the hydrologic characteristics of the Caloosahatchee River basin: Central and Southern Florida Flood Control District, Misc. Publ., Oct. 1955.
26. Soil Conservation Service. Report of investigations along the Caloosahatchee Canal, Hendry Conservation District, unpublished memorandum manuscript. Fort Lauderdale, Florida, May. 1948.
27. Stallman, Robert W. Preliminary findings on ground-water conditions relative to Area B flood-control plans, Miami, Florida: U. S. Geol. Survey Mimeog. Rept., Nov., Tallahassee, Florida. 1956.
28. Stringfield, V. T. Artesian water in the Florida peninsula. U. S. Geol. Survey Water-Supply Paper 773-C. 1936.
29. Vorhis, Robert C. Geology and ground water of the Fort Lauderdale area, Florida. Florida Geol. Survey Rept. of Inv. No. 6.

Effects of the Project on Agricultural Production and Land Usage[1]

JOHN C. STEPHENS AND ALEX CHAMBERLAIN[2]

When one attempts to assay the effects of the Central and Southern Florida Flood Control District works upon agricultural land usage and production, it should be borne in mind that there is usually a least a 10-year lag between the development of a new farming technique and its adoption by farmers. Remembering that the Flood Control District works were started about 1950, and that first efforts were directed primarily toward flood protection for east coastal urban areas rather than agricultural lands, it would be surprising if the impact of the Project on agricultural changes could be detected at the end of 1958, which is the latest year for which records are now available.

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[1]Joint contribution from Soil and Water Conservation Research Division, Agricultural Research Service, USDA; Central and Southern Florida Flood Control District; and Florida Agricultural Experiment Station.

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He has had extensive experience in agricultural geography and land economics. He joined the Central and Southern Florida Flood Control District in 1957 where he has been principally engaged in land use and economic geography studies as well as flood damage surveys and economic studies pertaining to the Project.

He is a member of the American Geographical Society, Association of American Geographers and the Soil and Crop Science Society of Florida.

Thus, we realize that the lack of up-to-date data—plus complexity of earlier information—makes our predictions somewhat tentative and subject to revision when additional information becomes available through future censuses or surveys. Nonetheless, we have attempted to assemble, analyze, and objectively interpret all the available information.

It was first thought that a plotting and analysis of the growth curve for the District's Project area might provide an approach for determining the effects of the District's program on crop production and land use adjustments. A change in the rate of agrarian growth at some particular period would indicate a new influence on conditions within the Project area, with an upward deviation indicating an improvement. But, could such an increase in the rate of agricultural production be credited solely to the impact of the Project works? Probably not. There are so many factors which can and have effected land use and agricultural production that it would be imprudent from such evidence alone to ascribe an improvement within the area to any one factor.

Experience has taught that it is very difficult to sort out and ascribe the influence of a given treatment on a large area. The problem of determining changes in rainfall-runoff relations on a watershed when better soil and water conservation practices are applied is illustrative; but indeed not easily resolved. The best approach to a problem of this nature is to choose at least two watersheds as nearly alike as possible, and to match the areas for a period of time to establish comparative ratings. The treatment on one basin is then changed and the other retained unchanged as a check for any resulting deviations.

SAMPLE AREAS

This method of comparative areas was chosen for our analysis. Selection of the sample space within the Project was restricted to lands where improvement work had been concentrated during the 10-year life of the Project. This space corresponded very closely to the area within the boundaries of the old Everglades Drainage District. Since the records used were mostly reported on a countywide basis—it being virtually impossible to separate data from within counties—the following contiguous counties were selected as representative of improved lands within the Project:

(1) Broward
(2) Dade
(3) Glades
(4) Hendry
(5) Martin
(6) Okeechobee
(7) Palm Beach

The above group of counties hereafter referred to as the *Treated Study Unit* comprises the eastern portion of State Economic Area No. 6.

By definition the State Economic Areas "have similar agricultural, demographic, climatic, physiographic, and cultural characteristics." Because of these similarities, the remaining counties in Economic Area No. 6, but outside the Flood Control District, plus Metropolitan Area B, were chosen for comparison with the area within the District's boundaries. Metropolitan Area B was included to compensate for Dade County. Counties included within the *Untreated Study Unit* are as follows:

(1) Charlotte
(2) Collier
(3) Hillsborough
(4) Lee
(5) Manatee
(6) Monroe
(7) Pinellas
(8) Sarasota

Thus, as shown in Figure 1, the sample space used in this study comprises Economic Area 6 plus Metropolitan Areas B and C. It is divided into two approximately equal subsamples: (1) the Treated Study Unit,

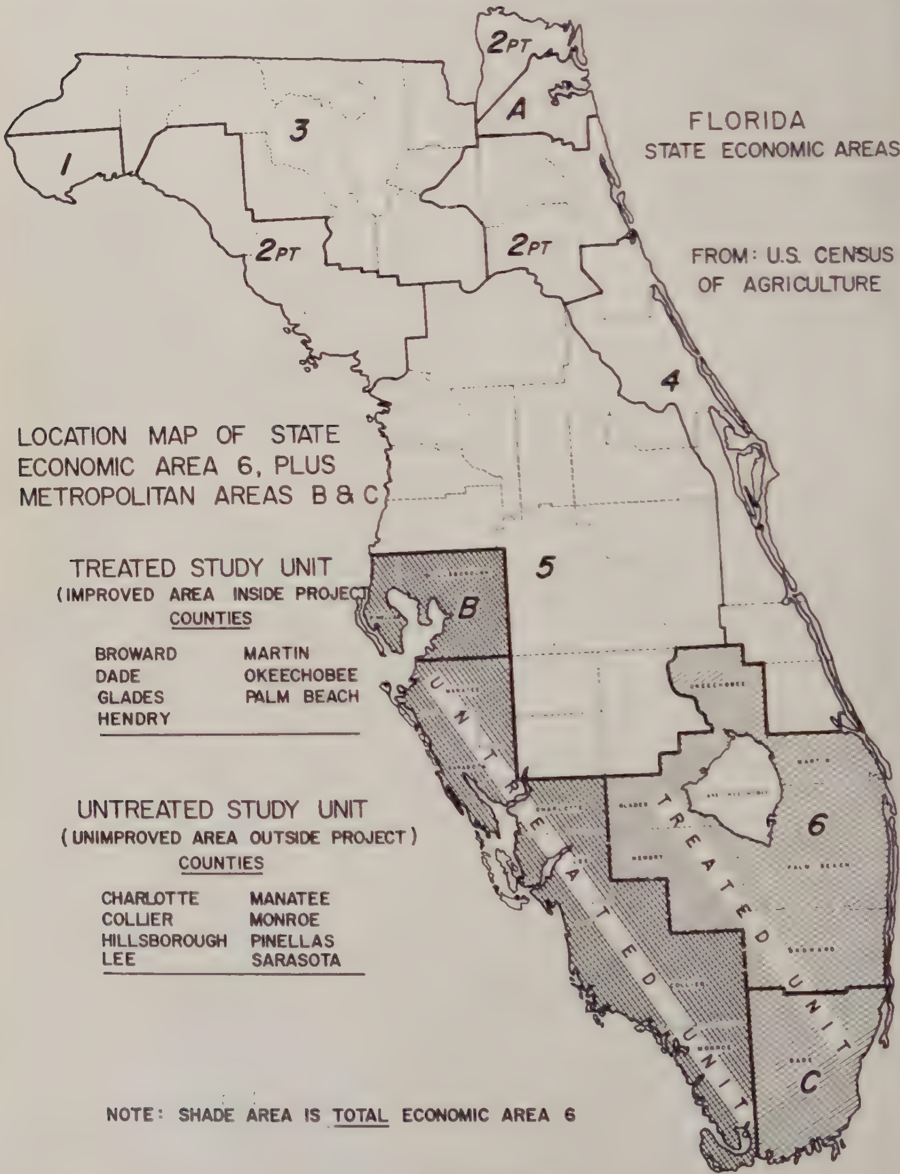


Fig. 1.—Location Map.

and 2) the Untreated Study Unit. This untreated unit is much superior to the state as a whole as a unit of comparison. Since census data for the economic areas are not available after 1955, it was decided to utilize, as an adjunct, annual statewide statistics which were available through 1958.

TRENDS IN AGRICULTURAL PRODUCTION

Figure 2 shows the growth rate for Florida's agricultural income from 1932 through 1958. This chart features two things: first, the annual receipts from crops, livestock, Federal subsidies, and value of home consumption; and second, census data plotted as bar graphs for each 5-year interval showing the relative value of tree fruit (including citrus) and nuts; vegetables; field crops; horticultural specialties; and livestock products. These 5-year benchmarks, or Measures of Production, also show the contrast between the census data and the data taken from annual volumes of "Agricultural Statistics."[3] Note that agricultural income as obtained from the USDA sources consistently exceeds that obtained from census data by approximately 20%. This discrepancy is due partly to the exclusion of the values of farm-forestry and poultry products in the census values; but primarily to the fact that the USDA's sources apparently provide more complete information about many items than the census has been able to obtain.

Figure 2 also reveals the rapid strides made in Florida's farm income, especially since 1940, and shows the proportion of income from each source. The dip during the years of 1947-48 in an otherwise steady growth rate is of evident interest. Local residents will recall it was the disastrous

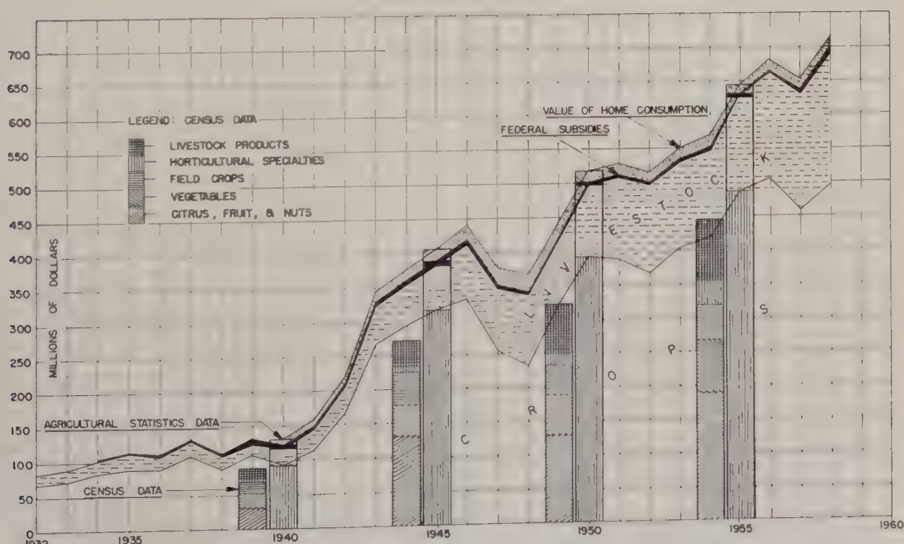


Fig. 2.—Increase in Florida Agricultural Income. (Annual breakdown in values—USDA Agricultural Statistics Five Year measures of production from agricultural census data.)

[3]U. S. Department of Agriculture. 1930-1958. Government Printing Office, Washington, D. C.

floods of these years which triggered the organization of the Central and Southern Florida Flood Control District.

It is apparent that the agricultural income for the state has increased tremendously in the last two decades. But, having common impetus, so has the national farm income. In Figure 3 we have balanced the increase in Florida's farm income against the national average as determined from "Agricultural Statistics." The United States total agricultural income was about \$5.3 billion in 1932, which increased to about \$36.4 billion by 1958. During this period, taking the ratio of Florida's farm income to national farm income in 1932 as a base of 100, Florida's portion of the national income was consistently below the base until 1943, touching a low of 78 in 1941. During World War II, Florida's portion of the national income approached the 1932 level, slightly exceeding it from 1944 until it plummeted during the year of flood and freeze in 1947.

By the early 1950's Florida's portion of the national income about equalled the 1932 level. Then, in 1953, it started increasing to about 30% above the 1932 level where it remained relatively stable until 1958, the last year of data available at the time of this study.

The Flood Control Project could possibly have begun to affect agricultural production by 1953 or 1954. Thus, it is an alluring speculation that the increase in the State's agricultural production was definitely correlated with the expansion of the District's flood control works, since the two periods coincide. However, encouraging as the trend may be, such an assumption at this stage is not fully warranted.

How well has the Project area (*Treated Study Unit*) prospered as compared to the whole state, which has fared handsomely, since 1953? Also, how well has the *Treated Study Unit* done when matched against the *Untreated Study Unit?*

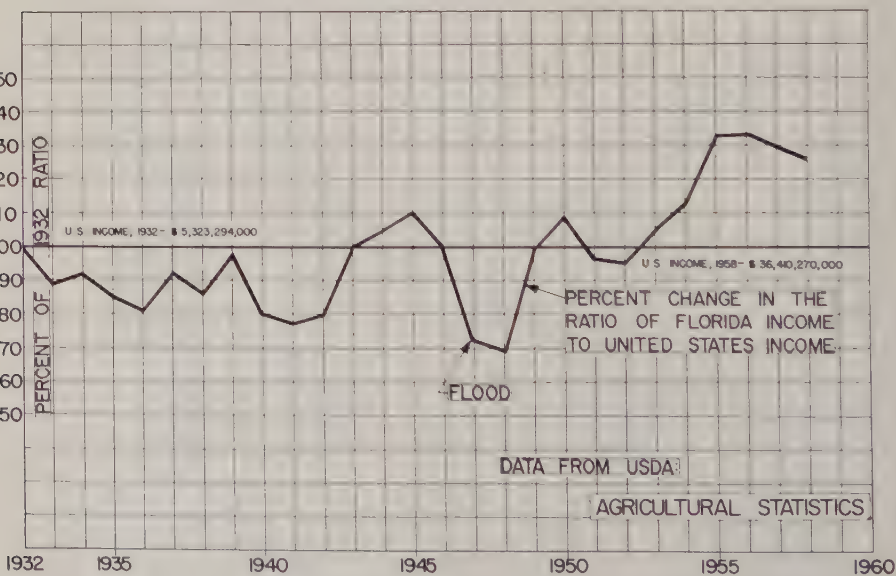


Fig. 3.—Trend of Total Farm Income Florida Compared to the United States. (1932 Ratio of 0.0154 taken as 100.)

The answers to these queries have been approached by first compiling Measures of Production for each county concerned. These Measures of Production are the combined yields from livestock products; horticultural specialties; field crops; vegetable crops; and tree fruits (including citrus) and nuts as obtained from census reports or, for 1958, from information furnished by County Agricultural Agents.

The counties were next grouped into two sets, one making up the *Treated Unit* and the other the *Untreated Unit*, so that the combined sets comprised the entire State Economic Area 6 plus Metropolitan Areas B and C (Figure 1). The two sets thus partition this whole sample space into two sub-sets so that each is the mathematical complement of the other.

Measures of Production for the *Treated* and *Untreated Units* are plotted as percentages of the total state farm income in Figure 4. Directly above each bar graph is listed the percentage contributed by the treated area as a fraction of the total sample space.

The chart shows that for the Agricultural Census of 1930 the counties comprising the *Treated Unit* yielded a little less than 12% of the total state farm income, whereas the counties comprising the *Untreated Unit* produced 14% of the state income. The *Treated Unit's* share of income for Economic Unit 6 was 44%. In contrast, the Census of 1955 shows that agricultural production for the *Treated Unit* was a little more than 21% of the state's total income while the *Untreated Unit's* proportionate share of state farm income declined to just over 10%. The counties within the Flood Control Project (*Treated Unit*) thus accounted for 67% of the farm production for the entire economic unit as contrasted with 33% for the counties outside the Project (*Untreated Unit*).

Figure 4 further shows that the *Treated Unit* has been producing an ever-increasing share of the total state agricultural income, with the single

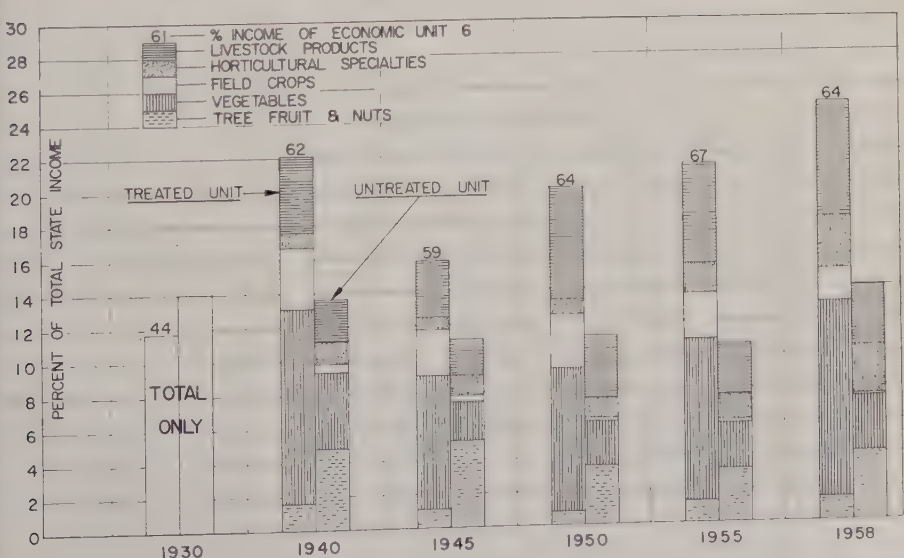


Fig. 4.—How "Measures of Production" in the Project Area and Check Area (Treated and Untreated Units) Compare to the State. (Note: Measures of production, 1930-1955, from Agricultural census data. 1958 from estimates by county agricultural agents.)

exception of census year 1940, when an exceptionally high return was received from vegetables produced within the *Treated Unit*. (One can readily see that the *Untreated Unit* has not matched this production trend.)

It is believed that final returns from the 1960 census will confirm the above trends, and that by the time the 1965 census data appear the *Treated Unit* will have pulled farther ahead; provided, of course that similar improvements are not made within the untreated area.

TRENDS IN LAND USE

In general, the same working hypothesis employed for studying changes in agricultural production was used for evaluating the effect of the Project on changes in land use, and to the degree suited, the same techniques and procedures were applied. The two prime sources of land use data were: first, the agricultural census from 1930 through 1955, and second, preliminary estimates made from the National Soil and Water Conservation Needs Inventory conducted by the United States Department of Agriculture in cooperation with State and local agencies.[4] The latter source provided land use current in 1958, and also projected acreage changes for 1975. These two sources were supplemented by excerpts from the Florida Crop and Livestock Reporting Service.

Figure 5 shows land use changes in Florida from 1930 to 1958 projected to the year 1975. The scale is semi-logarithmic for two reasons: first, to exaggerate the cropland scale for various crops which would have been indeterminate on a normal scale; and secondly, because it was observed from both the census and the conservation needs inventory acreage tallies that

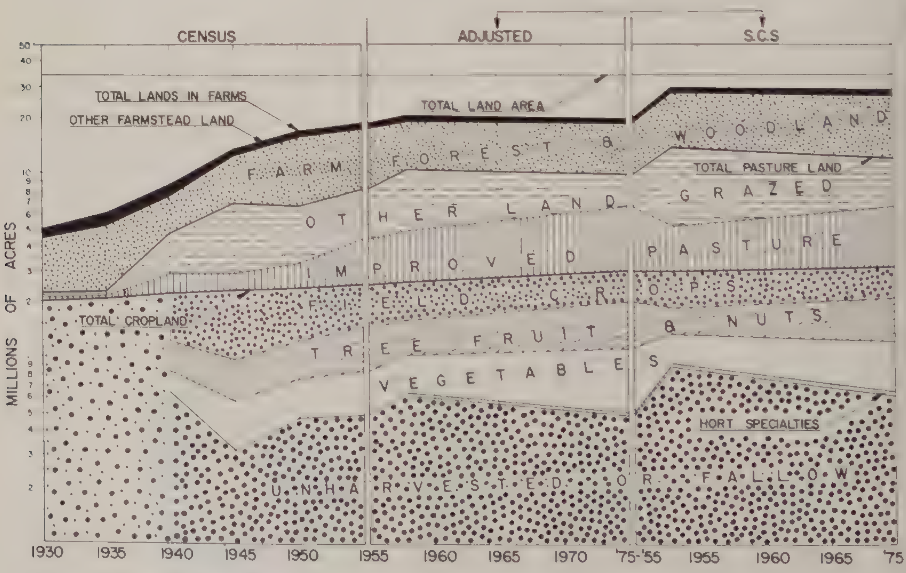


Fig. 5.—Land Use Change in Florida. (Note: Acreage plotted on semi-log scale.)

[4]Data for Florida were tabulated and made available by the Soil Conservation Service.

cropland acreage had expanded from 1930 through 1958 on an almost perfect growth curve. It was also noted that the estimated increase in cropland acreage for 1975 was an approximate extension of the same growth curve. The plotting, therefore, served as a convenient method to adjust the Florida portion of the National Conservation Needs Inventory (often referred to as the SCS survey) acreage tabulations to the same base as the census data.

Land use acreages from census sources are shown in the block on the left side of Figure 5, while the block on the right shows the same items from the Soil Conservation Service survey. With the exception of cropland, lines seldom match. This is because the census definition of farmlands, although modified from time to time, has always excluded productive commercial tracts—generally those containing more than a thousand acres of timber lands. On the other hand, SCS tabulated *all* agricultural lands including large tracts used for commercial production such as large pulp-wood holdings. In the center section of Figure 5 the SCS data have been adjusted to census data with cropland as the base. The lines now match, and land use acreages are comparable from 1930 through to 1975.

In 1958 total non-agricultural land in Florida was about 4.1 million acres: 1.1 million acres of built up and urban areas; 3.9 million acres of Federal Lands (military reservations, national parks, forests, etc.); conservation areas; and small water bodies. By 1975, non-agricultural land in the State is expected to increase to 6.2 million acres, with the built-up and urban areas more than doubling. Meanwhile, a slight reduction in Federal lands, conservation areas, and small water bodies is anticipated.

From the study of State statistics alone we have learned little as to the effect of the Project on land use, other than proving in general that agricultural lands have been steadily improved.

On the other hand, our instinctive belief and experience indicates that the *Treated Area* has played an important role in the statewide picture of better land use. Also, we have learned to reconcile the various sources of information, and have secured a better "feel" of the statistics, with greater confidence in our methods than could have been acquired from working with smaller units. In using small units, errors in counts or in determinations by the many individuals gathering the information might result in serious misconceptions. These are cancelled out and corrected by a "swamping process" for the entire State.

A comparison of land use changes in the *Treated* and *Untreated Units* is shown in Figure 6. Acreage is plotted to a normal scale from sums taken directly from data in the appendix. Since the discrepancy between the census and SCS methods of reckoning land-in-farms has not been rectified, there is considerable discontinuity between the 1955 and 1958 data.

Land use acreages in 1958 with projections for 1975 as derived from the Florida portion of the National Soil and Water Conservation Needs Inventory, are shown for the *Untreated* and *Treated Units* in Table 1.

Any attempt to interpret the projected 1975 estimates made in Table 1 is likely to result in controversy; especially the values for changes in urban development. However, we do wish to point out that change from agricultural to urban use is expected to take up only about 10% of the agricultural land, but variance in the density of population for urban and

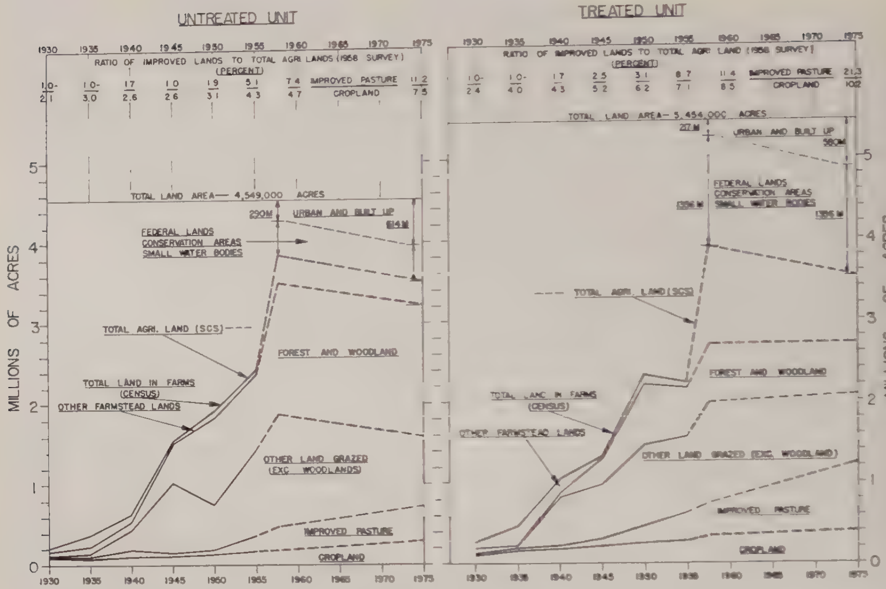


Fig. 6.—Comparison of Land Use Changes in Treated and Untreated Unit.

built-up areas is not necessarily linearly correlated with over-all population increase. Therefore an error of 100% in appraising the increase in population would not seriously affect the estimates of land remaining for farms and forestry in 1975.

It it shown in Figure 6 that the total land area in the *Treated Unit* is approximately a million acres more than in the *Untreated Unit*; but when urban and built-up areas, Federal lands, conservation areas, and small water bodies are deducted from both areas, about 3.8 million acres

TABLE 1.—LAND USE ACREAGES IN 1958 AND PROJECTIONS FOR 1975 FOR TREATED AND UNTREATED UNITS STATE ECONOMIC AREA 6.*

Land Use Category	Untreated Unit 1958	Untreated Unit Change	Untreated Unit 1975	Treated Unit 1958	Treated Unit Change	Treated Unit 1975
			(Thousand acres)			
Total Land Area	4,549	0	4,549	5,454	0	5,454
Non-Agricultural Land	709	324	1,033	1,573	363	1,936
Urban and Built-up	290	324	614	217	363	580
Federal Lands, Conserv. Areas Sm. Water Bodies	419	0	419	1,356	0	1,356
Agr. Land Available for Farms and Forestry	3,840	(−324)	3,516	3,881	(−363)	3,518
Cropland	180	107	287	330	65	395
Forest & Woodland	1,617	5	1,622	711	(−55)	656
Total Pasture & Range	1,697	(−386	1,311	1,667	20	1,687
Improved Pasture	283	147	430	444	385	829
Other Land Grazed	1,414	(−533)	881	1,223	(−365)	858
Other Farmstead Land	346	(−52)	294	1,173	(−393)	780

*From Florida portion of National Soil and Water Conservation Needs Inventory.

of land remain available for agricultural and forestry in each unit. The authors consider acreage available for agriculture and forestry as listed in the 1958 survey to be a suitable basis for calculating the improved land use changes for comparing the *Treated* and *Untreated Units* over the period of record. By assuming that improved pasture and cropland represents betterment of agricultural lands, we can now compute the ratio of improved lands to total agricultural lands (1958 survey) as shown in Table 2.

Improved lands for each unit have been plotted on a semi-log scale in Figure 7 to compare the rates of improvement. When the plotted points for the *Treated Unit* were connected by lines a typical growth curve resulted. Note that the improvement rate speeds up from 1950 to 1958, after which it is expected to level off. In following the same procedure for the *Untreated Unit* an anomaly existed for 1945. Probably the decrease for 1945 resulted from a difference in interpretation of the definition of "land in improved pasture or crops" within several counties. However, since 1945 was one of the World War II years, the reduced acreage is

TABLE 2.—A COMPARISON OF THE INCREASE IN RATIO OF IMPROVED LAND TO TOTAL AGRICULTURAL LAND BY CENSUS YEARS AND PROJECTED TO 1975.

Year	Untreated Unit			Treated Unit		
	Cropland	Improved Pasture	Total Betterment	Cropland	Improved Pasture	Total Betterment
			(Percent)			
1930	2.1	<1.0	≈2.5	2.4	<1.0	≈3.0
1935	3.0	<1.0	≈3.5	4.0	<1.0	≈4.5
1940	2.6	1.7	4.3	4.3	1.7	6.0
1945	2.6	1.0	3.6	5.2	2.5	7.7
1950	3.1	1.9	5.0	6.2	3.1	9.3
1955	4.3	5:1	9.4	7.1	8.7	15.8
1958	4.7	7.4	12.1	8.5	11.4	19.9
1975	7.5	11.2	18.7	10.2	21.3	31.5

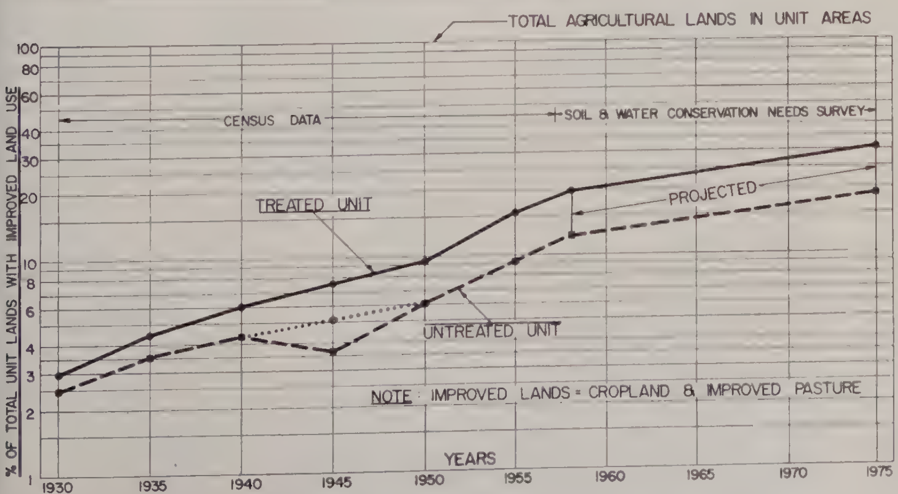


Fig. 7.—Growth of Improved Land Use.

possibly real and cannot be ignored. Figure 5 shows a slight dip for the State in improved pasture and some crops in 1945, even though such changes did not show up for the *Treated Unit*.

The growth curves for the two units are strikingly parallel with the exception of the 1945 anomaly for the *Untreated Unit*. It can be seen, however, that the *Treated Unit* is always above the *Untreated*, and close scrutiny reveals that the rate of improvement for the *Treated Unit* since 1950 is slightly better than for the *Untreated Unit*. However, in spite of such a trend, it would be improper to draw conclusions from these data alone as to the effects of the Project works in producing the increases since the difference between the growth curves is, from a mathematical standpoint, statistically not significant.

Indeed, because of the forementioned time lag in agrarian advances, it would be surprising if there were a clear contrast between the two units over such a relatively brief span of years since the installation of most of the Project works.

To interpret the development in terms of time, it might be helpful to focus attention on the organic soils area in Palm Beach County.

The peat and muck soils of the Upper Everglades Agricultural Area cover an expanse of approximately a thousand square miles that comprises both the potential and actual crop land in use for the Lake Okeechobee region. The construction of flood control works in these lands was given a priority second to protective works for the highly urbanized coastal area.

The change in the land use pattern for the Upper Everglades Agricultural Area between 1947 and 1957 is shown in Figures 8 and 9. The land use surveys were made by the U. S. Army Corps of Engineers.

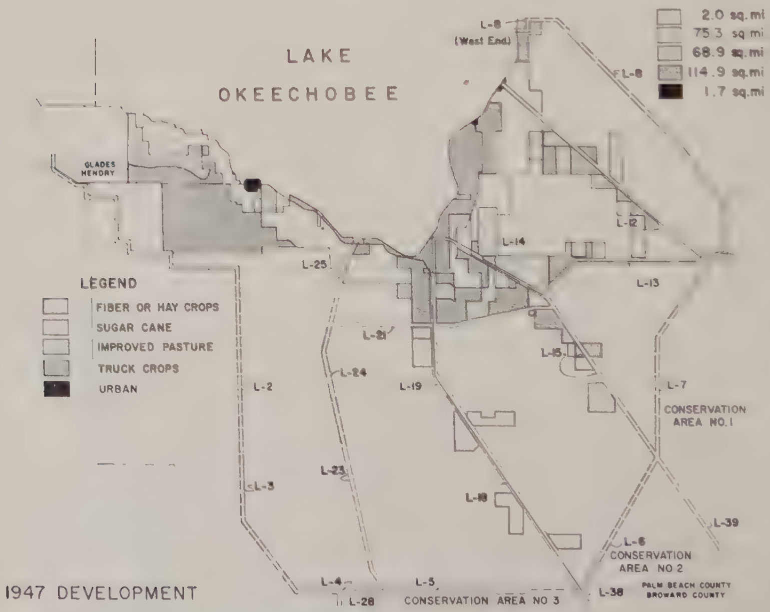


Fig. 8.—Lake Okeechobee-Everglades Agricultural Area 1947 Development.

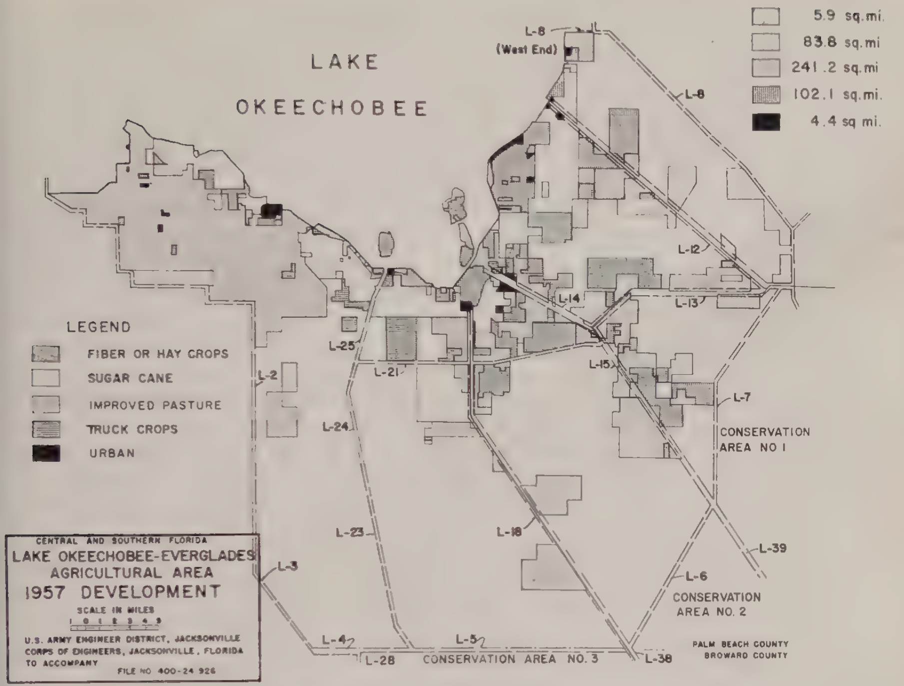


Fig. 9.—Lake Okeechobee-Everglades Agricultural Area 1957 Development.

Table 3 gives the main land uses for the years 1947, 1951 and 1957 in the Upper Everglades Agricultural Area.

The biggest increase took place between 1947 and 1951; mainly by development of improved pasture. The limited increase in improved land use since 1951 emphasizes the fact that mere installation of major works does not mean land will automatically be brought into production. Secondary and farm water control systems are also essential for expanded

TABLE 3.—PATTERN OF LAND USE CHANGE IN THE UPPER EVERGLADES AGRICULTURAL AREA BETWEEN 1947 AND 1957.

Land Use	1947	1951	1957
		(Square Miles)	
Truck Crops	114.89	90.42	102.12
Sugar Cane	75.31	75.24	83.78
Fiber and Hay	2.01	19.52	5.89
Improved Pasture	114.89	229.29	241.19
Urban	1.70	2.00*	4.41
TOTAL	262.80	416.47	437.39

*Estimate

development. These latter two requirements are expensive items and while the primary flood control works are a prerequisite for the secondary works, a real demand must exist before the necessary funds will be invested to bring additional lands into production.

This is demonstrated by the very recent demand for increased sugar production caused by the international political situation. The cane sugar producers in the Everglades are gambling millions of dollars to win, on a permanent basis, a share of the U. S. sugar market that once went to Cuba. In the current burst of domestic activity[5] three new sugar mills are being built in the vicinity, a fourth probably will be built, and the capacity of two existing will be expanded.

Cane planting for the new mills is already underway. Plantings shown in Table 3 for 1957 are expected to be expanded by 35,000 to 50,000 acres within the next two to three years. The intensive interest in growing cane in the Everglades has pushed the average price of suitable cane land from about $200 per acre six months ago to $300 or more per acre.

In other parts of the United States, sugar producers are proceeding cautiously—in striking contrast to the Everglades enterprises. They apparently fear that gains in output scored now may be only temporary. It is largely because of the productivity of the soil and the existence of the primary water control system that the gamble for permanently increased production seems so much more attractive in the Everglades than elsewhere.

SUMMARY

In summary, we feel that it is too soon to categorically evaluate the impact of the Flood Control Project on the increase in agricultural production and the relative improvement in land use. Yet, trends demonstrating a positive value of the Project to agriculture are definitely becoming apparent.

ACKNOWLEDGMENTS

The authors are sincerely grateful to Sally Reaney of the Flood Control District, and Bill Speir and Audrey Sullivan of the Agricultural Research Service for their aid in tracking down, assembling, and processing the voluminous mass of records and statistical material examined.

We would like to acknowledge all who have aided in this investigation, but so many individuals and organizations have helped that it is impossible to name and give credit to everyone involved. Among the Federal Agencies contributing were the Agricultural Research Service, the Agricultural Stabilization and Conservation Committee, the Agricultural marketing Service, and the Extension Service. Special thanks are due the Soil Conservation Service for making preliminary data available from the "1958 National Soil and Water Conservation Needs Inventory." The U. S. Army Corps of Engineers, Jacksonville District, furnished information on land use in the organic soils of Palm Beach County. Information obtained from the various census releases of the U. S. Department of Commerce, Bureau of the Census, was, of course, basic to the study.

[5]Reported in the Wall Street Journal, February 24, 1961.

In addition to the Central and Southern Florida Flood Control District, State agencies that contributed valuable aid include the University of Florida's College of Agriculture, Agricultural Experiment Station, Agricultural Extension Service, and the Florida State Marketing Bureau.

The authors are truly appreciative of the help of county agricultural agents who so obligingly completed questionaires relative to recent crop production and land use.

APPENDIX MATERIAL

The items tabulated in the appendix have been summarized from county data. Individual counties have not been shown because of space limitation. They are, however, on file at the Flood Control District and Agricultural Research Service offices for counties within State Economic Area 6 and Metropolitan Areas B and C. These additional statistics and or an explanation of the method of breakdown for the items can be obtained on request.

LAND UTILIZATION AND MEASURES OF AGRICULTURAL PRODUCTION

FLORIDA: ECONOMIC AREA 6 PLUS METROPOLITAN AREAS B & C: TREATED STUDY UNIT & UNTREATED CHECK UNIT

1930

Major Land Uses (acres) Measures of Production (Dollars)	State	Economic Area 6 and B & C	Treated Study Unit	Untreated Check Unit
		(Acres)		
Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Land in Farms	5,026,617	468,795	267,566	201,229
Forest and Woodland	1,891,838	75,001	16,480	58,521
Pasture and Range	477,742	62,377	32,838	29,545
Improved Pasture	301,432	24,141	15,425	8,716
Other Land Grazed	176,310	38,234	17,405	20,829
Cropland	1,969,234	175,676	94,807	80,869
Tree Fruits and Nuts Vegetables Field Crops (including cane) Nursery and Sod Difference*		NOT AVAILABLE		
Other Farmstead Land	687,803	155,741	123,447	32,294
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts) Non-Agricultural Lands Urban and Built-Up, Federal Lands, Conservation Areas, and Small Water Bodies		NOT AVAILABLE		
Total Value	$ 92,009,255	$ 23,011,782	$ 10,086,895	$ 12,924,887
Tree Fruits and Nuts Vegetables Field Crops (including cane) Horticultural Specialties (Sod, nursery, etc.) Livestock Products		NOT AVAILABLE		

1935

Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	6,048,406	807,306	445,637	361,669
Forest and Woodland	2,611,295	163,693	20,412	143,281
Pasture and Range				
Improved Pasture	347,860	42,373	25,573	16,820
Other Land Grazed				
Cropland	2,120,779	270,300	156,947	113,353
Tree Fruits and Nuts				
Vegetables				
Field Crops (including cane)		NOT AVAILABLE		
Nursery and Sod				
Difference*				
Other Farmstead Land	968,472	330,940	242,725	88,215
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts)				
Non-Agricultural Lands		NOT AVAILABLE		
Urban and Built-Up Federal Lands, Conservation Areas, and Small Water Bodies				
Total Value	$	$	$	$
Tree Fruits and Nuts				
Vegetables				
Field Crops (including cane)		NOT AVAILABLE		
Horticultural Specialties (Sod, nursery, etc.)				
Livestock Products				

1940

Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	8,337,708	1,666,909	1,040,511	626,398
Forest and Woodland	2,649,960	185,801	33,351	152,450
Pasture and Range	2,474,225	979,579	657,472	322,107
Improved Pasture	643,065	117,292	51,785	65,507
Other Land Grazed	1,831,160	862,287	605,687	256,600
Cropland	2,213,523	268,532	167,437	101,095
Tree Fruits and Nuts	373,110	55,776	13,337	42,439
Vegetables	194,450	104,870	82,740	22,130
Field Crops (including cane)	986,110	38,887	28,530	10,357
Nursery and Sod	1,000	350	350	
Difference*	−658,853	−68,597	−42,428	−26,169
Other Farmstead Land	1,000,000	232,997	182,251	50,746
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts)				
Non-Agricultural Lands		NOT AVAILABLE		
Urban and Built-Up, Federal Lands, Conservation Areas, and Small Water Bodies				

MEASURES OF PRODUCTION

Total Value	$ 87,814,268	$ 31,399,533	$ 19,425,862	$ 11,973,671
Tree Fruits and Nuts	30,132,844	5,595,105	1,415,635	4,179,470
Vegetables	21,892,568	14,114,053	10,134,643	3,979,410
Field Crops (including cane)	17,171,647	3,554,263	3,141,421	412,842
Horticultural Specialties (Sod, nursery, etc.)	3,929,469	1,935,656	751,278	1,184,378
Livestock Products	14,687,740	6,200,456	3,982,885	2,217,571

1945

Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	13,083,501	2,886,275	1,342,465	1,543,810
Forest and Woodland	5,801,860	804,519	326,127	478,392
Pasture and Range	4,568,278	1,696,830	754,085	942,745
Improved Pasture	562,563	133,717	95,615	38,102
Other Land Grazed	4,005,715	1,563,013	658,470	904,543
Cropland	2,314,631	299,216	200,904	98,312
Tree Fruits and Nuts	403,475	58,858	16,448	42,410
Vegetables	258,914	160,039	135,055	24,984
Field Crops (including cane)	1,327,712	48,445	30,471	17,974
Nursery and Sod	2,000	700	700	-
Difference*	−322,530	−31,174	−18,230	−12,944
Other Farmstead Land	398,732	85,800	61,349	24,451
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts) Non-Agricultural Lands Urban and Built-Up, Federal Lands, Conservation Areas, and Small Water Bodies		NOT AVAILABLE		
Total Value	$270,690,116	$ 73,011,361	$ 42,910,105	$ 30,101,256
Tree Fruits and Nuts	131,204,251	16,720,858	2,810,601	13,910,257
Vegetables	46,833,969	28,027,734	21,730,137	6,297,597
Field Crops (including cane)	46,348,233	8,407,452	7,277,378	1,130,074
Horticultural Specialties (Sod, nursery, etc.)	9,603,590	5,163,935	2,025,736	3,138,199
Livestock Products	36,700,073	14,691,382	9,066,253	5,625,129

1950

Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	16,527,536	4,299,072	2,377,645	1,921,427
Forest and Woodland	9,049,842	1,824,589	739,257	1,085,332
Pasture and Range	4,332,444	1,838,717	1,219,018	619,699
Improved Pasture	936,853	190,802	119,168	71,634
Other Land Grazed	3,395,591	1,647,915	1,099,850	548,065
Cropland	2,387,569	362,921	242,474	120,447
Tree Fruits and Nuts	498,669	109,535	19,213	90,322
Vegetables	277,329	148,086	122,504	25,582
Field Crops (including cane)	1,123,351	47,598	41,157	6,441
Nursery and Sod	19,324	10,085	4,641	5,444
Difference*	−468,896	−47,617	−54,959	-7,312
Other Farmstead Land	757,681	272,845	176,896	95,949
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts) Non-Agricultural Lands Urban and Built-Up, Federal Lands, Conservation Areas, and Small Water Bodies		NOT AVAILABLE		
Total Value	$321,290,350	$100,436,145	$ 64,355,358	$ 36,060,787
Tree Fruits and Nuts	129,931,152	14,128,431	2,583,725	11,544,706
Vegetables	59,742,708	35,545,383	27,211,331	8,334,052
Field Crops (including cane)	42,467,280	10,710,760	10,169,200	541,560
Horticultural Specialties (Sod, nursery, etc.)	17,373,143	6,946,247	3,063,682	3,882,565
Livestock Products	71,776,067	33,105,324	21,347,420	11,757,904

1955

Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	18,161,675	4,717,401	2,299,029	2,418,372
Forest and Woodland	8,975,652	1,579,993	608,855	971,138
Pasture and Range	5,658,472	2,549,829	1,305,332	1,244,497
Improved Pasture	1,939,126	532,600	337,154	195,446
Other Land Grazed	3,719,346	2,017,229	968,178	1,049,051
Cropland	2,520,969	438,770	275,169	163,601
Tree Fruits and Nuts	1,242,840	167,427	47,012	120,415
Vegetables	379,150	206,775	159,230	47,545
Field Crops (including cane)	1,059,070	63,661	54,279	9,382
Nursery and Sod	23,322	19,151	12,753	6,398
Difference*	+183,413	+18,244	−1,895	+20,139
Other Farmstead Land	1,006,582	148,809	109,673	39,136
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts) Non-Agricultural Lands Urban and Built-Up, Federal Lands, Conservation Areas, and Small Water Bodies		NOT AVAILABLE		
Total Value	$444,799,442	$142,154,979	$ 94,828,882	$ 47,326,037
Tree Fruits and Nuts	188,827,830	20,083,632	5,783,250	14,300,382
Vegetables	78,267,235	54,509,431	42,601,312	11,908,319
Field Crops (including cane)	60,538,930	13,093,224	11,991,865	1,101,359
Horticultural Specialties (Sod, nursery, etc.)	27,601,310	14,701,526	8,081,656	6,619,870
Livestock Products	89,564,137	39,766,906	26,370,799	13,396,107

1958

Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	29,728,586	7,721,392	3,880,777	3,840,615
Forest and Woodland	16,445,333	2,327,886	711,210	1,616,676
Pasture and Range	7,424,986	3,363,819	1,666,527	1,697,292
Improved Pasture	2,330,505	726,313	443,470	282,843
Other Land Grazed	5,094,481	2,637,506	1,223,057	1,414,449
Cropland	2,944,071	509,424	329,519	179,905
Tree Fruit and Nuts	560,700	108,225	32,775	75,450
Vegetables	370,200	216,565	180,405	36,160
Field Crops (including cane)	1,077,478	55,940	51,600	4,340
Nursery and Sod	24,000	12,370	8,610	3,760
Difference*	−911,963	−116,323	−56,128	−60,195
Other Farmstead Land	2,914,196	1,520,263	1,173,521	346,742
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts)	(9,706,586)			
Non-Agricultural Lands	4,999,094	2,281,808	1,573,303	708,505
Urban and Built-Up Federal Lands	1,100,024	507,232	217,302	289,930
Conservation Areas and Small Water Bodies	3,899,070	1,774,576	1,356,001	418,575
Total Value	$664,556,500	$258,267,268	$165,612,268	$ 92,655,000
Tree Fruits and Nuts	267,890,500	36,711,144	9,343,644	27,367,500
Vegetables	146,466,000	99,403,132	77,378,132	22,025,000
Field Crops (including cane)	67,000,000	14,312,892	13,612,592	700,300

Horticultural Specialties (Sod, nursery, etc.)	33,000,000	39,703,700	20,291,500	19,412,200
Livestock Products	150,200,000	68,136,400	44,986,400	23,150,000

1975

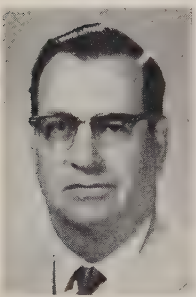
Total Land Area	34,727,680	10,003,200	5,454,080	4,549,120
Available for Agriculture and Forestry				
Land in Farms	28,515,922	7,033,779	3,517,993	3,515,786
Forest and Woodland	16,057,016	2,278,415	655,527	1,622,888
Pasture and Range	6,969,277	2,996,739	1,685,291	1,311,448
Improved Pasture	3,657,897	1,257,471	827,503	429,968
Other Land Grazed	3,311,380	1,739,268	857,788	881,480
Cropland	3,136,661	682,130	394,843	287,287
Tree Fruit and Nuts	874,000			
Vegetables	596,000			
Field Crops (including cane)	1,000,000			
Nursery and Sod	50,000			
Difference*	—616,661			
Other Farmstead Land	2,352,968	1,074,495	780,332	294,163
Agricultural Land Not in Farms (Commercial timber and large unproductive tracts)	(8,771,000)			
Non-Agricultural Lands	6,211,758	2,969,421	1,936,087	1,033,334
Urban and Built-Up Federal Lands	2,371,195	1,194,000	580,000	614,000
Conservation Areas and Small Water Bodies	3,840,563	1,775,421	1,356,087	419,334
Total Value	$	$	$	$
Tree Fruits and Nuts		NOT AVAILABLE		
Vegetables				
Field Crops (including cane)				
Horticultural Specialties (Sod, nursery, etc.)				
Livestock Products				

*Cropland minus total acreage of Fruits & Nuts, Vegetables, Field Crops, and Nursery and Sod. A minus quantity indicates unharvested cropland: a plus quantity indicates double cropping.

The Upper St. Johns River Basin[1]

HAROLD A. SCOTT[2]

SECTION I. HISTORICAL AND GENERAL CONSIDERATIONS



General:

The Upper St. Johns River Basin is considered to be that area extending northward, from State Road No. 68 in the vicinity of Ft. Pierce, to Lake Harney in a north and south direction, and between the low coastal divide of the Kissimmee River on the west. The drainage area consists of about 1,910 square miles. The St. Johns River is separated from the Indian River by a low coastal divide 3 to 10 miles wide.

The Basin is characterized by elevations reaching 80 feet on the western divide and 30 feet on the eastern divide; whereas the river bottom has an elevation of about 24.5 feet in the vicinity of Lake Wilmington sloping down to about zero elevation at Lake Harney. The river is composed of heavy marsh areas with Lake Wilmington near the headwaters, and extending downstream is Lake Hellen Blazes, Sawgrass Lake, Lake Washington, Lake Poinsett, Puzzle Lake and Lake Harney. At places between the lakes the channel is indistinct and almost non-existing until the vicinity of Lake Poinsett. From there to Lake Harney there is a more-or-less well defined channel.

Originally, during flood periods, water drained not only to the north, down the St. Johns River, but it drained to the east into Indian River across the narrow divide through numerous creeks connecting the two river basins. Among those natural drains were Sebastian River, Elbow, Goat, Turkey and Crane Creeks, and later the man-made Ellis Canal.

[1]A copy of the Upper St. Johns River Basin proposed plan of improvement is available by writing to the Central and Southern Florida Flood Control District, 901 Evernia Street West Palm Beach, Florida.

[2]Manager, Tampa Office, Reynolds, Smith and Hills, Architects and Engineers and Consultant, Central and Southern Florida Flood Control District, West Palm Beach.

Mr. Harold A. Scott received his Bachelor of Science degree in Civil Engineering from the University of South Dakota. He was engaged in general engineering practice in South Dakota and New York during 1931-1935. He was with the Corps of Engineers in Eastport, Maine and Providence, Rhode Island until 1940 when he was transferred to the Jacksonville, Florida, District of the Corps. He was responsible for developing the Central and Southern Florida Flood Control Project as well as planning, budgeting, research, model studies, etc., from 1940 to 1954.

He joined the firm of Reynolds, Smith and Hills in 1954 where he was in charge of the Gas Department, preparation of economic feasibility reports and designs for natural gas distribution systems; preparation of miscellaneous reports and general planning. He became manager of the Tampa Branch Office 1960-1961. He is a Project Development Engineer at the present time.

Mr. Scott is a member of the American Society of Civil Engineers, National Society of Professional Engineers; a senior member of the Florida Engineering Society, Executive Committee, U. S. Commission in Irrigation and Drainage, 1952-1957, and represented the Corps of Engineers' Department of the Army at the Second Congress, International Commission on Irrigation and Drainage, Algiers, Algeria, North Africa, 1954. He is a registered engineer in the State of Florida.

Perhaps there were other creeks which have been cut-off through the development of the area.

Initial Development:

During the period from 1915 to 1920, a survey was made by Isham Randolph for the Upper St. Johns Drainage District. That District was expanded to 369,082 acres and extended from Lake Harney to the Fellsmere Drainage District line. Strangely enough, the plans for that district coincide rather closely with all recent plans for improvement of the Basin. However, the District provided for use of natural creeks and canals draining into Indian River. Such outlets would have made it much easier and more feasible for controlling the water in the Basin than draining it north through the St. Johns River to the Atlantic Ocean.

As Florida developed, numerous drainage districts were constructed on the divide between Indian River and the St. Johns River. The most notable of those drainage districts are listed in Table 1.

TABLE 1.—DRAINAGE DISTRICTS ON THE COASTAL DIVIDE

Name	Outlet	Area in Square Miles
Melbourne- Tillman	Turkey Creek	94
Fellsmere	Sebastian River	72
Sebastian	Sebastian River	17.5
Indian River Farm	Taylor Creek	74.5
Ft. Pierce Farms	Taylor Creek	--
North St. Lucie	Taylor Creek and North Fork St. Lucie River	-

All of those districts extend back into the St. Johns River Basin. Besides the natural waterways, canals have been cut into the districts draining to Indian River. As a result of the construction of those drainage districts extending from Ft. Pierce to the vicinity of Melbourne, all natural drainage from the St. Johns River to Indian River has been cut off. Individual land owners have added to the drainage area of Indian River by building dikes into the St. Johns River Basin and canals to drain the diked areas.

In recent years numerous land developers on both sides of the St. Johns Basin have constructed dikes out into the Basin so that the remaining natural waterway is less than a quarter of a mile wide in some locations. This has served to restrict the natural flow of the water to the northward and caused higher stages in the upper basin.

Damages:

Severe damages have been suffered, not only in the Upper St. Johns River Basin, but also downstream of Lake Harney and particularly in the Sanford Area. In 1933 and again in 1960, flood waters were in the streets at Sanford and caused severe damage to streets and numerous residences along the waterfront. In the Upper St. Johns Basin the damages consisted primarily of ruined pastures, broken dikes, flooded crop, the drowning of cattle, and similar agricultural damages. Perhaps the greatest damage was that of taking land out of production for periods extending up to 9 months at a time. Normally, those lands are most productive either for cattle or crops.

Plans of Development:

The approval of the Comprehensive Plan for Central and Southern Florida for Flood Control and Other Purposes[3] by the Federal Government in 1948, and the creation of the Central and Southern Florida for Flood Control District by the State of Florida, initiated a new area of planning for the Upper St. Johns River Basin. However, it was not until 1954 that the project in the St. John River Basin was authorized by the Federal Government, thereby making it eligible for funds from the Federal and State Governments. Because of this lag of time between authorization of the initial plan for the Southern part of the District in 1948, and the Upper St. Johns in 1954, the Central and Southern Florida Flood Control District obtained Legislative approval of what is now called the "Flood Plain Zone Act." This Act established a potential reservoir storage area from 3.5 miles south of State Road 60 north to Lake Harney. No new construction was to be allowed in the Zone without a permit from the District. This area was considered to be the natural flood plain of the river. The Act also served to stop development of these lands which are too low for the most part, and not suitable for economic agricultural endeavors.

The slow progress in planning, in the Basin, made it necessary to go to the Legislature and amend this Act which expired in 1959. The Amendment in 1959 provided for extension until such time as the Act may be terminated by law. This has proved a stop-gap measure, but has not brought about development in the Basin.

The slowness of development can be laid to the conflict of interests in the Basin. Those interests consist of farming, recreation, wildlife, those interests along Indian River that do not want to see any drainage from the St. Johns River to Indian River, real estate developers and many others. Relatively few of the interests were inclined to give a little. Most insisted that theirs was the primary interest in the Basin and that therefore they should be served over and above all others. This went on for a number of years until in 1960 a new plan was developed by the Flood Control District.

The Comprehensive Plan[3] was developed by the Corps of Engineers in 1947. It was partially authorized by the Federal Government in 1948. However, full authorization was not obtained until 1954.

This plan called for storage areas in the Basin and four outlets to Indian River. Those outlets to Indian River were to be used only during emergency periods when storage and discharge down the St. Johns River could not control floods. The outlets would assist in reducing flood stages in the vicinity of Sanford and prevent flood damages. Considerable objection was raised against the Comprehensive Plan by certain Indian River interests and also by recreational and wildlife interests. A large measure of the objections was due to lack of understanding of the plan.

Because of the objections, the Flood Control District, working with local committees in each county in the Basin, proceeded to develop a new plan which reduced the drainage to Indian River. This plan was submitted to the Corps of Engineers for review in 1956.

The Corps of Engineers reviewed this plan and then drew up a new

[3]House Document 643, 80th Congress, Second Session.

plan[4] increasing the size, cost and number of acres of land which were placed in reservoir areas. The scope was so great that it was economically not feasible for the District or the Florida State Government to take part in the plan. The plan was objected to by the Flood Control District and planning remained practically dormant for almost two years.

The Attitude of the Residents:

The great interest of Brevard and Indian River Counties to obtain early orderly development and protection of the natural resources in the Basin, caused them to retain the services of Engineering Consultants to work with the Flood Control District and the Corps of Engineers. A new plan was developed by the District for flood control and water conservation. This plan, dated May 1960, went back to many of the original concepts of the Comprehensive Plan. It provided for only one outlet, through the Sebastian River, to Indian River. It contained four reservoirs for storage of flood waters and also for conservation of water during low flows. Perhaps the most noticeable change from any of the previous plans was the creation of a new reservoir in the Puzzle Lake area, between State Roads 46 and 50, which would have tremendous benefits, particularly in Brevard County.

One of the otustanding features of this plan was its favorable acceptance by those most concerned. The people were advised that, "any plan in the Upper St. Johns River Basin, in order to be acceptable to the over-all community, must be a compromise plan which gives full consideration to each of the conflicting interest groups and considers each as a segment of the community to receive equal benefits and therefore be responsible for equal contribution in terms of group or personal sacrifice toward implementing the plan." This philosophy was accepted by the majority of the groups and the communities. It was approved by Brevard, Indian River, Seminole and Orange Counties, which would stand to benefit most by any plan.

Opposition to the plan was held primarily only by those who refused to recognize the scope and features of the plan and the ultimate benefits to be received. Those opposed generally refused to realize that those lands to be contained in the plan were privately owned and that the owners may develop them in any way which they see fit. Consequently, they could be lost for conservation purposes if no action was taken.

Benefits:

By far the greater share of benefits from a water control project in the Upper St. Johns Basin will accrue to the urban, industrial and tourist areas along Indian River and westwardly of the Coastal Ridge, even though the project itself must be justified largely by agricultural benefits within the Basin. While these benefits, to areas adjacent to the Basin, cannot be fully evaluated in terms of dollars they can be listed as:

1. A dependable and potable water supply without which the Regions growth potential cannot be attained.
2. Retention of a large measure of the fresh water fisheries, wildlife and recreational values of the Basin, which are rapidly and surely being depleted by uncontrolled and uninhibited development of lands within

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[4]Part III—Upper St. Johns River Basin and Related Areas. Supplement 2 General Design Memorandum Upper St. Johns River Basin.

the marsh and prairie areas. These values will accrue largely to the nearby urban areas when made generally accessible and usable.

3. Increased agricultural marketing values along the railroad and intrastate highways.
4. Controlled discharge of fresh water to Indian River in lieu of uncontrolled discharge of all drainage from most of the lands east of the River, which will result from uninhibited development and consequent increased flood stages in the River Basin. It must be pointed out that this will likely take place to a considerable degree in any case, since all of these lands are subject to gravity drainage to Indian River and its implementation is dependent only upon formation of drainage districts or other agencies impowered to acquire rights of way. Control and stabilization of river stage regimen will however tend to decrease this trend, and to the degree that it does take place, project discharges would be decreased.

SECTION 2—THE PROPOSED PLAN FOR WATER CONTROL

General:

The proposed plan of improvement studied by the Florida Control District is composed essentially of the following components which are shown in generalized form on Plate 1:

1. Seven small detention reservoirs on the western slope of the Basin which will serve to delay excessive flood runoff from their tributary areas.
2. Four valley reservoirs defined for the most part by the boundaries of the legally zoned flood plain. Lands within the reservoir boundaries to be placed in public ownership in fee, either by donation or by purchase at a nominal cost. Flowage easements on lands outside the reservoir boundaries would be acquired to the extent needed.
3. Farm type dikes to be constructed by the individual landowners and at their individual option. The limit of such diking would be the reservoir boundaries.
4. Channelization as required to provide conveyance capacity through the reservoirs.
5. One west-east canal to discharge floodwater, in excess of that which can be stored in the reservoir or discharged downstream, to the Atlantic Ocean by way of Sebastian Inlet.
6. The necessary water level controls with which to provide optimum water levels in the reservoirs and prevent overdrainage and salt intrusion in the areas adjacent to the west-east canal.

The Upland Detention Reservoirs:

The seven small reservoirs proposed to be installed on the western slopes of the Basin and their physical characteristics are shown in Table 2.

The purpose of these reservoirs would be to delay surface runoff to the valley reservoirs from about 437 square miles. They would also serve as water conservation reservoirs during the dry season and provide irrigation benefit to about 60,000 acres of land.

Because of the nature of the benefits to be derived from these upland reservoirs, which have the character of farm ponds and because seasonable usage for grazing will be available it is not expected that any costs will be

TABLE 2.—CHARACTERISTICS OF THE UPLAND RESERVOIRS

Name	Area Acres	Flood Storage capacity acre feet	Pool Elevation ft. msl. Min.	Max.	Drainage Area sq. mi.
Ft. Drum Creek	4,990	28,490	40.0	50.0	88
Blue Cypress Creek	2,100	8,500	40.0	50.0	84
Padgett Branch No. 2	1,100	2,600	48	55	21.3
Padgett Branch No. 1	2,250	7,800	40	50	11.8
Jane Green Creek No. 3	2,750	10,500	35	45	103.0
Jane Green Creek No. 2	1,100	6,400	35	45	78.4
Jane Green Creek No. 1	6,500	37,400	25	35	50.6

involved in acquiring the necessary water storage rights in the reservoir areas.

The Valley Reservoir:

The physical characteristics of the four proposed valley reservoirs are shown in Table 3.

The boundaries of these reservoirs as considered in this study are generally identical with the flood plain zone as defined in Chapter 30542, Section 5-A of the laws of Florida. The principal exception is in Puzzle Lake Reservoir where a considerable area outside of the zone must be included in order to protect downstream areas from flood stages higher than would occur under existing conditions and the Lake Wilmington Reservoir where additional storage capacity for both conservation and flood control storage.

It is expected, because of individual landowners plans for more limited development, that additional lands outside the planned reservoir boundaries can be acquired in fee. To the extent that this is done the discharge of water from the basin will be reduced and water supply benefits increased. The final detail planning for the Basin, presumably by the Corps of Engineers, would include these additional areas in the reservoirs.

Provisicns of small boat navigation facilities throughout the entire length of the Basin should be installed at project cost, if possible. If it should be established that Federal State Project funds cannot be used for this purpose then other means should be sought to provide the facilities at the time of project installation.

It is proposed in the plan that no project levees be built around the valley reservoirs. In lieu of project levees it is proposed that flowage easements be paid to land owners to compensate for annually storing water

TABLE 3.—CHARACTERISTICS OF THE VALLEY RESERVOIRS

Name	Area Sq. Miles	Flood Storage Capacity Acre Feet	Conservation Storage Capacity Acre Feet
Lake Wilmington	54.2	139,000	170,000
Lake Washington	48.0	140,000	147,000
Lake Poinsett	31.0	100,000	77,500
Puzzle Lake	52.9	212,000	131,000

on lands whose elevations are below those of water conservation pools. Each land owner would be privileged to prevent flooding of his lands by constructing dikes at the reservoir boundary or at any line outside the reservoir areas. Moneys paid for flowage easements and land purchase should be sufficient to finance the major portion of the cost of dikes.

Special Water Conveyance Features:

a. Canalization Below Lake Poinsett.

The conveyance capacity in the floodway just below Lake Poinsett is much too small to discharge the outflow from Poinsett Reservoir. Enlargement of the river channel for a distance of about 8 miles is required to provide the necessary capacity.

b. Floodway South of State Road 60.

The lands within the Upper St. Johns drainage Basin south of State Road 60 are being rapidly developed primarily for citrus production. There is no natural conveyance channel to discharge excess water from the area to the St. Johns floodway. In the past this area has acted as a great, natural water storage reservoir from which excess water flowed slowly northward. Development of the area will require that a conveyance facility be provided of adequate capacity to discharge the excess water to the north at high rates of flow and at stages that will not endanger adjacent farm dikes.

Discharge to Indian River:

Reduction of the Basin's storage capacity by diking along the proposed reservoir boundaries would so drastically reduce the flood storage capacity still existing that the increase in rate of discharge would endanger the valley below the north District boundary, at least as far downstream as Deland.

This reduction in storage area has been underway for many years and is continuing. About 60% of the natural flood storage area south of Lake Washington has been appropriated already and as a consequence flood stages in the Basin, both above and below Lake Harney, have been increasing. The further reduction of storage capacity by installation of farm dikes at the proposed reservoir boundaries will make it necessary to discharge excess flood water eastwardly to Indian River. The fact that a great majority of land owners agreed to establishment of the Flood Plain Zone within its legal boundary indicates that they do intend to develop their lands to that line with or without a project. It is proposed that this discharge be made by way of Sebastian Creek which flows into Indian River directly opposite Sebastian Inlet.

The canal required to convey discharge during the critical period of flood runoff to Sebastion Creek would be provided with at least two controls; one to regulate discharge from Lake Wilmington Reservoir and one to prevent overdrainage of the area traversed by the canal and to prevent salt water intrusion into the fresh ground water supply of the area. It is proposed that this canal be located along the alignment of the existing Fellsmere Drainage District main outlet canal and that it be used as an outlet for lands both to the north and south. Negotations with the Fellsmere Drainage District are underway and studies will be made to determine the practicability of using the existing canal and dikes as floodway, rather than excavate the costly canal required to regulate the reservoir.

SECTION 3—HYDROLOGY AND HYDRAULICS

Design Flood:

In the Upper St. Johns Basin the more critical flood situations occured near the end of wet seasons (June to October) during which there has been a continuous build up of water stored in the Basin. Under such conditions, if intense rainfall occurs, such as usually accompanies a tropical storm, in September or early October the entire marsh and prairie area of the Basin is severely flooded for long periods of time.

The 1953 flood was of this nature and the causative rainfall and measured runoff of that flood season were used as a basis for determining the hydraulic requirements for protection of the Basin against flood damage. This flood has been determined by the Corps of Engineers to be of once in 20-year magnitude based upon volume of runoff.

A similar flood occurred in the fall of 1960. Stages were equally as high throughout the basin and particularly in the Sanford area.

A large proportion of the lands on the eastern side of the Basin have already developed behind dikes and drained by gravity to Indian River. It is likely that additional lands will be so drained. Therefore, it is considered unlikely that runoff to the St. Johns Basin from this area will increase except as affected by pumping of lands that are now gravity drained.

It is expected that much of the land on the western slope will be developed for agricultural use. However, these lands are not subject to intense agricultural development without an artificial water supply. Some of them are at elevations such that water supply from the proposed project reservoirs will be economically available. The higher lands however must be provided with a supply at higher elevations. The creation of many small ponds, or reservoirs, as a part of successful development for agricultural use is considered to be necessary. Increase in rate and volume of runoff is expected to be minimized by storage in these ponds.

Routings were made of the design flood hydrographs and it was found that the peek flood stage at Sanford would be 8 feet mean sea level. This could be further reduced by additional storage in the Upper Basin or additional canals to Indian River.

The Federal State Project could provide additional flood damage protection to the area north of the Flood Control District without objection from the District if land acquisition or other District costs were not involved. The Project proposed herein is concerned with consummation of the District's responsibility to the District area.

The critical characteristics of the hydragraphs are shown in Table 4.

Regulation Schedules:

Regulation schedules, in general, were developed in consideration of the natural stage regimen, the agricultural water supply requirements, practicability of diking, fish and wildlife preservation and retention of a continuously adequate water supply for domestic and industrial use.

It is evident that all these considerations cannot be met to the optimum degree and that compromise is necessary. The regulation schedules developed for design purposes are subject to a considerable degree of change and variation.

Both the water supply and storage capacity of the Lake Wilmington Reservoir are small in comparison with its potential irrigation area. In

TABLE 4.—CHARACTERISTICS OF DESIGN FLOOD HYDROGRAPHS

Reservoir Outlet	Maximum Stage ft. msl.	Maximum[1] Discharge cfs.	Total Discharge 1000 a. ft.	No. Days of Maximum Discharge
Lake Wilmington	26.2			
Downstream		4,800		
Diversion		6,000	536	35
Lake Washington	20.9	6,600		
Lake Poinsett	16.8	7,800		
Puzzle Lake	12.0	12.200		

[1]Maximum discharge during critical period of flood. In some instances higher rates of discharge were made prior to the critical period.

order to provide a major portion of the irrigation needs it was necessary that nearly the entire reservoir capacity be assigned to water conservation. Only the top foot of depth was reserved for excess runoff storage during the flood season.

Upland Reservoirs:

Controls to be provided in the reservoirs along the west slope of the river basin, as in the main reservoirs, would be provided with features which would allow them to be operated as both flood control and water conservation reservoirs. However, their primary benefit to the over-all project would be through flood storage that would provide for the reduction of runoff peaks from the western river slopes.

Water would be released from the reservoirs during the normally dry spring months to minimum levels at the start of the rainy season about June 1. During the normally wet summer and fall months a fixed crest overflow feature in the control structures would permit spillway-type regulation. This type of operation is desirable since due to the number and inaccessibility of the required structures, operator inspection should be kept to a minimum.

Following the rainy season, additional storage above the spillway crests would be provided by gates or stop-logs to permit maximum water conservation through the dryer winter months.

Lake Wilmington Reservoir:

This reservoir is the largest of the valley reservoirs both with respect to area and storage capacity. Top of the conservation pool is at 26.0 ft. msl. and bottom of the pool is at 20 ft. msl., at which elevation no water supply would be released except for domestic purposes.

The reservoir would be provided with two gated control structures, one discharging into Lake Washington Reservoir and another eastwardly to Sebastian Canal. The Flood Control pool stage at its crest would be 26.2 ft. msl. at the discharging control and approximately 26.8 at State Road 60.

Excess flood water from this reservoir would discharge into the Lake Washington Reservoir to the extent that capacity is available in the three lower reservoirs to absorb the discharge without exceeding regulation stages. Flood Waters in excess of that would be discharged to Indian River through the Sebastian Canal.

The reservoir storage capacity is 139,000 acre ft. for flood control and 170,000 acre ft. for water conservation. Lands considered to be irrigable from this reservoir total 283,000 acres.

Lake Washington Reservoir:

The conservation pool in this reservoir is between elevations 21.0 and 15.0 ft. msl. Design flood stage is 20.9 ft. msl. at the control and 21.4 or less at the upper end depending upon the discharge out of Lake Wilmington Reservoir. Bottom of the flood control pool is 17.0.

The reservoir capacity for flood control is 140,000 acre feet and for water conservation 147,000 acre feet. The reservoir would be provided with one gated control structure to discharge northwardly into Lake Poinsett Reservoir. Lands considered to be irrigable from this reservoir total 118,400 acres.

Lake Poinsett Reservoir:

The conservation pool is between 16.0 and 11.0 ft. msl. Design flood peek stage is 16.8 ft. msl. at the control and 17.1 ft. msl. at the upper end of the reservoir. Bottom of the flood control pool is at 12.0.

The reservoir capacity for flood control is 100,000 acre feet and for water conservation 77,500 acre feet. One control structure would be provided for discharge into Puzzle Lake Reservoir. Lands considered to be irrigable from this reservoir total 46,000 acres.

Puzzle Lake Reservoir:

The control structure for this reservoir would be located above the confluence of the Econlochatchee with the St. Johns River. Its primary flood control purpose would be to prevent increased flood stages below the Flood Control District, from the vicinity of Sanford to Deland.

The regulation schedule proposed for this reservoir is somewhat different frcm those of the three valley reservoirs above. In order to provide protection to the downstream valley, as the Upper St. Johns floodway and storage area is appropriated by diking, it is necessary that a flood storage pool be provided above the water conservation pool.

The conservation pool is between 10.0 and 5.0 ft. msl. Top of the flood control pool is 12.0 at the control and 14.8 at the upper end. Bottom of the flood control pool is at 5.0. The reservoir capacity for flood control is 212,000 acre feet and for water conservation 131,000 acre feet. One control structure would be provided to discharge northwardly to the natural river.

During flood periods when water is being stored above 10.0 ft. msl. it will be necessary that a small area adjacent to the reservoir dikes be pumped or discharged below the structure. Lands considered to be irrigable from this reservoir total 62,900 acres.

SECTION 4—WATER SUPPLY AND UTILIZATION

General:

The only known planning, by any agency or interest, calculated to preserve any part of the water supply and its attendant conservation values, is that of the Federal State Flood Control Project under jurisdiction of the Corps of Engineers and the Central and Southern Florida Flood Control District. These agencies must base project justification on flood

control and water supply benefits. The reservoir areas proposed are believed to be lands whose probable costs justify their use for water conservation and flood control. Additional lands, if available under that criterion, will be added. Enhancement of wildlife values might well justify the addition of other lands, especially suited to that purpose, by agencies authorized to commit appropriations to that end.

The capacity to store water provided by the proposed reservoirs is not entirely adequate to completely serve the potential agricultural needs of the irrigable area of the Basin. The annual droughts that now occur would be eliminated.

Water Supply:

The Basin water supply for the period of record (1942-1955) has been computed and published by the Corps of Engineers in General Design Memorandum Part III, Supplement 2, for the conservation areas proposed in that publication. Those water supply values, pro-rated according to tributary areas have been used in the period of record routings.

The Basin supply for October 1955 to December 1956, was computed from stream flow records at the Melbourne and Christmas gauging stations with consideration of ground water table, storage change, rainfall and evapo-transpiration.

Water Demand:

a. Agricultural.

By far the greater water supply demand will be that for irrigation of agricultural lands. The irrigation areas and capacities for each reservoir are shown in Table 5.

b. Domestic and Industrial

One of the most important benefits to be derived from a water conservation project in the Upper St. Johns Basin is expected to be provision of a dependable water supply for the urban coastal area to serve a large portion of its projected population of 1,000,000. In these studies it has been assumed that it eventually will serve a population of 50,000.

c. Wildlife and Recreation

The Upper St. Johns Basin is an extremely valuable and important wildlife and fresh-water fishing area. Its importance is far more than local and state-wide, it is national and international as well.

There are no apparent funds available, now or in the foreseeable future, with which these lands may be acquired except to the extent that such acquisition can be justified for flood control and general water control purposes under the Central and Southern Florida Flood Control Project.

TABLE 5.—RESERVOIR WATER SUPPLIES

Reservoir	Irrigation Area sq. miles	Irrigation Area acres	Reservoir Capacity Acre-Ft.	Stored Water Supply Inches
Lake Wilmington	441	283,000	163,000	6.9
Lake Washington	185	118,400	147,000	14.9
Lake Poinsett	73	46,700	77,500	19.9
Puzzle Lake	98	62,700	131,000	25.0
Total	797	510,800	518,500	—

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SECTION 5—ECONOMICS ANALYSIS

Costs:

Detail cost analyses have not been made for the purposes of this plan. Structural costs have generally been based upon the estimated costs of similar structures made by the Corps of Engineers and reported in General Design Memorandum Part III, Supplements 1 and 2.

Other costs are based upon generalized analysis and are of a preliminary nature. Table 6 shows the breakdown of the total estimated cost of \$17,330,000 and average annual cost of \$696,000.

Water Control Benefits:

a. Flood Damage Reduction

Damage studies made by the Corps of Engineers and reported in General Design Memorandum Part III, Supplement 2, were used as the basis for estimating flood damage reduction consequent to the proposed project. Plate 66 of the General Design Memorandum shows the curves of flood damage versus frequency as computed by the Corps for the area south of Lake Pointett. The flood damage area after deducting the area included in the proposed conservation areas was about 135 square miles. The flood damage area of the project proposed herein is 400 square miles after deducting areas included in reservoirs. Average annual

TABLE 6.—ESTIMATED COSTS OF PROPOSED PROJECT

Name	Total Costs Dollars		Dollars Annual Costs
Lake Wilmington Controls	2,000,000[1]		
Lake Washington Control	1,000,000[1]		
Lake Poinsett Control	1,200,000[1]		
Puzzle Lake Control	1,500,000[1]		
Upland Reservoir Controls	2,000,000		
Sebastian Diversion Canal	2,000,000[2]		
Canal Downstream from Lake Poinsett	600,000		
Engineering and Other Costs	2,000,000		
Flowage Easements	1,260,000[3]		
Cost Sharing Total		13,560,000	
Reservoir Lands	3,570,000[4]		
Floodway, South of State Road 60	200,000		
Total Local Costs		3,770,000	
TOTAL		17,330,000	610,000
Operation and Maintenance			86,000
TOTAL			696,000
Federal Share	10,848,000[5]		
Local Share	6,482,000[6]		

[1]Includes 2 structures for Lake Wilmington and one for other three reservations.

[2]Includes Control at lower end.

[3]These payments are based on average cost of tieback dikes.

[4]These payments should be adequate to finance a major portion of the cost of riverward dikes.

[5]80% of cost sharing total.

[6]20% of cost sharing total plus Local costs.

flood damage under existing conditions is $2,080,000 and under project conditions $640,000 showing a flood damage reduction benefit of $1,440,000.

b. Irrigation

Project benefits assignable to the provision of an irrigation water supply to an area of approximately 510,000 acres were estimated by means of the Drought-Loss Relation Curves for Improved Pasture, derived by the Corps of Engineers and published as Plate 68 in GDM Part III, Supplement 2. Annual drought damage was computed for the period of stream flow record for the potential irrigation area of each reservior under existing conditions and with the project. The difference, or the average annual irrigation benefit, is $949,000.

Domestic and Industrial Water Supply Benefits:

The population growth potential of the coastal area adjacent to the Upper St. Johns Basin is very great. Estimates range upwards toward a million population for Brevard and Indian River Counties. This potential cannot be reached unless a source of water supply for domestic and correlative industrial use is provided. Local ground water sources are inadequate and of unsatisfactory quality even for existing populations. Distant groundwater supplies are costly and also limited.

Wildlife and Recreation Benefits:

Pending an analysis and evaluation of project impact upon Fish and Wildlife resources of the Basin by the State Game and Freshwater Fish Commission, a preliminary lay analysis has been made in order to recognize in this report the inherent values of wildlife and recreation.

a. The Upper St. Johns Basin

This evaluation of the fish and wildlife resources in the Upper St. Johns Basin is based upon the assumption that without a water conservation project these resources will be totally destroyed in time by uncontrolled development of the marsh and prairie lands by private interests.

It is evident that even with the project as now proposed, waterfowl use of the Basin would be seriously affected if private lands were developed fully in accordance with the assumptions made in these studies. Shallow water feeding grounds would be greatly reduced.

With the proposed project, fishing values should be retained in most of the Basin about as they now exist and recreational use should increase as access and facilities are increased and improved. Development of the Puzzle Lake Reservoir would greatly enhance the fisheries, wildlife and recreational values of the area north of Lake Poinsett.

b. Indian River

During the periods of high discharge from the Lake Wilmington Reservoir to Indian River, fisheries in the vicinity of Sebastian Inlet may be adversely affected. However, the time of such discharge will coincide with the maximum runoff from the several drainage districts and other lands already, and irrevocably, discharging flood runoff to the river. Total discharge from six of the major inflowing streams in the vicinity of Sebastian Inlet has been measured at 11,026 cubic feet per second. An estimated 4,850 cubic feet per second of that comes from the St. Johns River Basin. Lesser, but nevertheless high, inflows occur almost continuously during wet seasons nearly every year.

The addition of some 6,000 cubic feet per second to the existing high inflow of fresh water would have its adverse effect but whatever damage

may be done to fisheries in the vicinity by inflowing fresh water must have been in large measure accomplished already by existing inflows.

Economic Feasibility:

In demonstrating economic feasibility only agricultural benefits accruing to the Upper St. Johns Basin itself have been cited in Table 7. No attempt has been made to evaluate the benefits to adjacent areas or to the State at large.

TABLE 7.—AVERAGE ANNUAL AGRICULTURAL BENEFITS

Flood Damage Reduction	$ 1,440,000
Irrigation	949,000
TOTAL	$ 2,389,000

The benefit to cost ratio is $\frac{\$2,389,000}{696,000} = 3.4$

The studies resulting in this report have been directed principally towards establishing the fact of economic feasibility for an attainable water control project. It has been demonstrated that such a project can be justified by agricultural benefits alone. It is expected that further studies by the District and the Corps of Engineers will result in dollar evaluations of other benefits which might well equal those determined for agriculture.

These additional benefits will include:

1. Provisions of adequate domestic and industrial water supplies.
2. Retention and possible enhancement of existing freshwater fisheries.
3. Enhancement of recreational values.
4. Increase in marketing and shipping of agricultural products.

SECTION 6—DISCUSSION AND CONCLUSIONS

Discussion:

The Upper St. Johns River Basin is a large area rich in natural resources. To date, development has proceeded in a haphazard manner to the detriment of wildlife, fish and recreation. Flooding and droughts have caused severe damage. Numerous plans have been made for water control. The most recent plan is that developed by the Central and Southern Florida Flood Control District. That plan is now being considered by the Corps of Engineer.

Conclusions:

The latest plan developed by the District will come close to obtaining the maximum possible benefits and yet protect the natural wildlife and fish resources. The plan has received general acceptance by the general public and particularly by those land owners in the Upper St. Johns River Basin. While this plan may not be final in many ways, it is believed to be a satisfactory basis for development of the Basin.

PARTICULAR ATTENTION IS CALLED TO A MAP OF THIS PROPOSED PLAN THAT HAS BEEN PROVIDED BY THE DISTRICT FOR INCLUSION AT THE BACK OF THIS PROCEEDINGS, UNATTACHED AND IN ITS ORIGINAL SCALE FOR THOSE WHO MAY BE INTERESTED IN SAVING IT FOR FUTURE REFERENCE.

NOTE: The author has drawn freely from the Report of the Upper St. Johns River Basin, dated May, 1960, prepared by the Central and Southern Florida Flood Control District. Without the benefit of that Report, this paper would have lacked many important details.

Economic Factors in the Central and Southern Florida Project

HERBERT C. GEE[1]

INTRODUCTION

A full understanding of the economic basis on which the Central and Southern Florida Project was authorized and is now being constructed and operated requires some knowledge of the past history of Federal Flood Control Legislation.

The Federal Government initiated its participation in nation wide flood control activities by passage of the Flood Control Act of June 22, 1936. In the Declaration of Policy found in Section 1 of this Act, the following language appears:

"It is the sense of Congress that flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with states, their political subdivisions, and localities thereof; that investigations and improvements of rivers and other waterways including watersheds thereof, for flood control purposes are in the interests of the general welfare; that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof for flood control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected."

This natural Flood Control Act specifies certain requirements of local cooperation which are expected as minimum contributions from states

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For fifteen years Colonel Gee was a member of the U. S. Army Corps of Engineers, during which time he was District Engineer, Jacksonville District, from 1942 through 1943.

Colonel Gee is engaged in private engineering practice and is consultant to the Central and Southern Florida Flood Control District.

He is a member of the American Society of Civil Engineers, a fellow of Florida Engineering Society (President in 1956), a life member of the Permanent International Association of Navigation Congresses, a member of the Society of American Military Engineers and the Soil and Crop Science Society of Florida.

He is a registered Professional Engineer, State of Florida; holds a national registration with the National Association of State Boards of Engineering Examiners; and is included in *Who's Who in Engineering*.

He is a member of the American Society of Civil Engineers, Committee on Coastal Engineering, and a consultant to the U. S. Senate Select Committee on National Water Resources.

and political subdivisions thereof on cooperative flood control projects. Briefly these requirements are that local interests shall:

(a) Provide all lands, easements, and rights of way.
(b) Hold and save the United States free from damages due to the construction works.
(c) Maintain and operate all works after completion.

From time to time the original requirements of local cooperation have been modified by the Congress. However, the most significant change directly affecting the Central and Southern Florida Project was the inclusion of language in the Flood Control Act of December 22, 1944 which redefined flood control to include major drainage. The pertinent language is quoted:

> "Section 2. That the words 'flood control' as used in Section 1 of the Act of June 22, 1936 shall be construed to include channel and major drainage improvements, . . ."

The enactment of this provision into law on December 22, 1944 set the stage for the subsequent authorization of the Central and Southern Florida Project.

When one considers that this project is the first major venture of the Corps of Engineers into the field of channel and major drainage improvements subsequent to the Flood Control Act of December 22, 1944, it is not surprising that in arriving at a mutually agreeable basis for cost sharing as between local interests and the Federal Government, the experience of the Bureau of Reclamation in the 17 Western States was examined most closely by the Corps of Engineers.

PROJECT DESCRIPTION

The project for Central and Southern Florida involves an area of 15,570 square miles in central and southern Florida. The area includes all or part of 18 counties of the state and is organized as a drainage district by special legislation in 1949 which created the Central and Southern Florida Flood Control District. The political subdivision of the state is responsible for fulfilling all of the requirements of local cooperation under the Federal Project as authorized in the Flood Control Act of June 30, 1948, and subsequent acts.

The major drainage areas included within the District are the Basin of the Upper St. Johns River; the North Fork St. Lucie River; the Kissimmee River and other tributaries to Lake Okeechobee; the Caloosahatchee River and St. Lucie Canals which are the principal outlets of Lake Okeechobee; and the wild marshlands of the Everglades, together with numerous coastal drainage areas, many of which have been improved by local interests.

The project area is that part of the eastern slope of the Florida peninsula located south of the latitude of Cape Canaveral and the City of Orlando. The District area is generally bounded on the west by the ridge which divides waters which flow to the Atlantic from those which reach the Gulf of Mexico. An important consideration which led to the inclusion of all the various drainage basins in the project is the fact that the many watersheds mentioned function in periods of high water

as a single watershed with intermingling and exchange of waters during periods of heavy rainfall and high stages.

The key reservoir of the entire project is Lake Okeechobee. Under the authorized plan this lake will be completely surrounded by high levees capable of confining the waters of the lake to the lake area even during periods of hurricane storms. The lake provides a safe storage area for surplus waters during the rainy season with provision for reuse of these waters in the interest of irrigation, domestic water supply, ground water recharge and prevention of salt intrusion.

A second major water storage area is provided in the wild lands of the Everglades south and east of the Lake Okeechobee agricultural area where surplus waters can be stored during the rainy season for reuse during the subsequent dry period of each year.

Conservation storage is also provided under the project in the chain of lakes in the headwaters of the Kissimmee River Basin and in the Upper St. Johns Basin. In the latter area, the capacity of the few existing lakes will be augmented by the aquisition of certain marshlands to be used as water conservation areas.

The above described works to provide additional water storage are augmented by protective levees around the Everglades Agricultural Area, together with adequate pumping capacity to remove surplus water at the rate of 3/4 of an inch per 24 hours by pumping into Lake Okeechobee and the conservation areas.

Throughout the District, major channel improvement, water control structures, and a complex system of levees are combined to produce important benefits of flood control, navigation, water conservation, land enhancement, fish and wild life, salt intrusion prevention and recreation.

ECONOMIC EVALUATION IN THE ORIGINAL PROJECT REPORT

House Document 643, 80th Congress, 2nd Session

As a result of the comprehensive studies which followed immediately after the devastating floods of 1947, the Corps of Engineers submitted to Congress its report on the Central and Southern Florida Project designated House Document 643, 80th Congress, 2nd Session. In this document the Corps of Engineers reported that a project then estimated to cost $208,-000,000 and with a benefit to cost ratio of 2.05 to 1 was feasible from an engineering standpoint and should be authorized in the interests of minimizing flood damage, protection of life and property and conservation of water resources in this large area of central and southern Florida.

In the same report, the question of division of costs between local interests and the Federal Government is discussed in considerable detail. It was found in the benefit analysis that of the total benefits cited 35.4% were attributable to flood control, navigation and preservation of fish and wild life. These activities and consequent benefits were considered to be a Federal responsibiliy. The second major category of benefits was that chargeable to increased use of land. This component amounted to 64.6% of total benefits cited. The Corps of Engineers recommended to Congress that the major component of benefits, that chargeable to increased use of land, should result in that percent of the cost of the project which corresponds to the percentage of land enhancement benefit being divided between the Federal Government and local interests.

Here the experience of the 17 Western States in the Federal Reclamation Project was the basis of the recommendation that local interests assume 60% of this compotent of cost and Federal Government 40%.

The total cost to be divided between Federal and local interets is arrived at by adding construction, lands and relocations and the present worth of annual maintenance. The resulting total economic costs cited is $279 million dollars. Thirty-five point four percent (35.4%) of this total economic cost is charged to the Federal Government, as is 40% of that component chargeable to increased land use. The total of these two Federal shares then becomes 171 million dollars while the local share is 108 million dollars.

In the final analysis, the project as recommended to Congress in 1948 recommends the Federal Government bear 61% of the total economic cost while local interests bear 39% of this cost.

House Document 643, 80th Congress recommends that the local share toward project cost be met by local interests, first by the local sponsoring district assuming all reponsibility for lands, rights of way and easements, then estimated to cost $3,898,000; second, local district to assume local responsibility for relocations then estimated to cost $4,044,000; third, local district to assume responsibility for maintenance and operation with an estimated present worth of $71,162,000. These three designated activities amount to $79,104,000. In order to cover the entire local share an additional contribution in cash amounting to $29,152,000 was recommended to the Congress.

This is the basis on which the project was launched by Federal authorization on June 30, 1948, and describes the total commitment which the Flood Control District, as representative of the interest of the State of Florida, assumed at the time the project was initiated. It is most interesting to examine subsequent publications and see how the original commitment of local interest has changed through the years.

ECONOMIC RE-VALUATION OF THE PROJECT IN 1957

(House Document 186, 85th Congress, 1st Session)

A full understanding of this economic re-evaluation ordered by the Congress can be faciliated by comparing cost estimate in the 1948 report with those contained in the 1957 report. The corresponding figures are tabulated below.

Attention is invited to the fact that estimated construction cost is reduced almost 40 million dollars, lands and relocations have been increased almost fourfold while the present worth of the local maintenance effort is decreased from 71 to 28 million. As a consequence of these changes

COST COMPARISON 1948-1957

	1948	1957
Construction	$200,193,000	$159,090,000
Lands & Relocation	7,942,000	27,346,000
Maintenance (present worth)		
Federal		2,254,000
Local	71,162,000	28,390,000
Total Economic Cost	$279,297,000	$217,080,000

the total economic cost, as reported in 1957, is 60 million dollars less than the same figure in 1948.

The basic philosophy on which the recommendations contained in the report of 1957 are based is described briefly as follows: benefits are computed and divided into two major catagories, the first, those for which a Federal overriding responsibility is recognized, such as flood control, navigation, protection of fish and wild life; a second catagory of benefits generally land enhancement in character and described as "local benefits" comprises the balance of total benefits estimated. Benefits for which there is a Federal responsibility amount to 44% of total benefits cited, local benefits account for the remaining 56%. The Federal benefits percentage applied against total construction cost result in the Federal Government assuming 69,999,000 dollars of estimated construction cost. The remaining construction cost amounting to $89,090,000 is divided equally between the Federal Government and local interest. Local interests are fully responsible for lands and relocations and are required to assume the responsibility for maintenance and operation of all works except those associated with the regulation of Lake Okeechobee, the Cross-State Navigation Project and the structures to control stages in the three water conservation areas of the Everglades.

The computation of total cost allocated to the Federal and local interets results in a final recommendation to the Congress to the effect that works authorized in the Flood Control Act of 1954 be carried out on a basis similar to that specified for Phase 1 of the Project authorized in 1948, except that the 15% cash contribution to construction cost specified for Phase 1 be increased to 20% for Phase 2.

The review report summarizes the recommendations with this statement, "Thus on the basis of present cost estimates, local interests would contribute about 16.4 million dollars more than the present monetary limit of $29,152,000 as specified in House Document 643, 80th Congress."

ADDITIONAL ECONOMIC ANALYSIS OF PROJECT ADDITIONS

The Flood Control District did not immediately consent to a modification of the basis of cost sharing as set forth in House Document 186, 85th Congress, 1st Session. However, the recommendations of the Corps of Engineers were accepted by the Congress and the new basis for cost-sharing applicable to Phase 2, the 1954 authorization, were enacted into law in the Florida Control Act of July 3, 1958. Local interests assumed, perhaps erroneously, that the new basis for cost sharing would be applied generally to all feature of the comprehensive multiple purpose project except Phase 1, the original 1948 authorization.

This assumption proved to be incorrect when in 1959 Senate Document 53, 86th Congress, 1st Session, a report on the Nicodemus Slough area, was published. This report recommends still another basis for cost sharing under the over-all project. The project features in question were estimated in March 1957 to cost $463,000.00. For this small addition to the project, the Corps of Engineers recommended and the Congress approved a requirement that local interests meet all the presently prevailing requirements of local cooperation and increase the cash contribution from 20% as previously authorized to 31.5% with respect to these works only,

Local interests protested bitterly the introduction of still another basis

for cost sharing in this long range multiple purpose project for the development of the water resources of central and southern Florida. These objections were repeated in testimony before the Senate Committee on Public Works. However, the Congress accepted the recommendations of the Corps of Engineers and authorized the project with this independent basis for cost sharing.

The Flood Control District has attemped on at least two occasions in its annual report to the Bureau of the Budget to impress upon the responsible Federal officials the importance of adhering with one over-all basis for cost sharing in this large project. Ample evidence exists to demontrate conclusively that local interests are paying more of the total economic cost of this project than of any comparable undertaking in the entire Federal water resources program.

The Flood Control District, as the authorized representative of local interests in the project, is continuing its efforts to convince the Federal agencies and the Congress that some uniformity of cost sharing should be established throughout the project.

CONCLUSIONS AND RECOMMENDATIONS

From the foregoing study of the history of cost sharing under the Central and Southern Florida Project, little has been said about the ratio of benefits to costs. The original project was reported to Congress in 1948 with an indicated benefit to cost ratio of 2.05 to 1. The 1957 review of the project reflects a benefit to cost ratio of 3.7 to 1. Obviously, it is a sound conclusion that this project represents a wise investment of Federal and local funds and that the benefits to be produced will greatly exceed costs involved.

It is the recommendation of the writer that no effort be spared by local interests and the Corps of Engineers to come to grips with the problem of uniform cost sharing under the Central and Southern Florida Project. It is further recommended that the cost sharing basis authorized in the Flood Control Act of 1958 be accepted for all features of the project except Phase I which is now authorized, or which will be authorized in the near future.

The Immediate Impact of the Project on Land Use in the Indian Prairie—Lake Istokpoga Area

KENNETH A. HARRIS[1]

The Indian Prairie-Lake Istokpoga Area encompasses approximately 500 square miles. Starting on the eastward slopes of the Lake Placid Ridge it extends easterly to the Kissimmee River Watershed and, from Lake Istokpoga on the north extending southeasterly to Lake Okeechobee.

PHYSICAL AND HYDROLOGICAL CHARACTERISTICS

The overall watershed is shaped similar to a huge basin dipping toward the southeast. The northern and western extremities have elevations of 90 to 135 ft. M. S. L. The land slopes to Lake Okeechobee where its elevaion ranges from 18 to 20 ft. M.S.L. The slopes are at their steepest near the ridge and become very gentle to flat as one leaves this elevated section.

Climatological data for the area is seriously lacking. We assume therefore that it is similar to other south Florida conditions having an average rainfall of 50 inches per year ranging from 30 to 82 inches. The temperatures seem to conform to sub-tropical conditions although the extremes appear to be somewhat wider than the south Florida coastal areas.

PRE-PROJECT LAND USE

The majority of the area away from the ridge has been subjected to inundation for six to eight months out of each year but sometimes for the entire year. Attempts to develop areas for improved pasture and vegetable crops usually have been in vain unless suitable dikes were constructed around the area and pumps provided for drainage as required. This has resulted in ill feeling among the neighboring landowners in several instances. Since general outlets for the regional waters were very limited the land adjacent to drained areas were not necessarily made less useable even though the water may have become slightly deeper and remained somewhat longer.

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Kenneth A. Harris was born in North Judson, Indiana, in 1923 and educated in Indiana schools. He entered Purdue but his University work was interrupted to enter the U. S. Marine Corps where he served in the Pacific as a corporal. Following his return to the University he received the B.S. degree in Agricultural Engineering in 1948, being a member of the first class graduated in that department at Purdue. After working for some time in Alaska he returned to the U.S. and spent five years as an agricultural engineer with the Soil Conservation Service following a brief period as Assistant Agricultural Engineer at the Everglades Experiment Station. He is now a registered engineer in the State of Florida.

Some areas on the long slopes of the ridge are used for specialized crops as caladiums, Easter lilies and vegetables and the ridge areas for citrus. The majority of the areas, however, has been used primarily as native range for cattle when and where the water receded. Thus the total production from this vast section has been extremely low.

RESPONSE TO PROJECT CONSTRUCTION

When the plans for construction of the Indian Prairie Canal, now known as Canal C-40, Harney Pond Canal (C-41), Canal C-39A and Canal C-41A were being planned and finally given the green light for construction, the landowners were no less happy than a youngster on the last day of school. They recognized that the potential production they had been dreaming of for a long time now could become a reality.

Canals C-40, C-41 and C-39A are now constructed along with their pertinent structures. Already thousands of acres are developed and producing vegetables. Improved pasture and citrus groves have been planted. Many thousands of acres are being planned for additional development to these crops.

The Project, as constructed, has provided outlet facilities for drainage and flood waters and serves as excellent sources of irrigation water for the areas served. With the completion of the Project the entire area will be so served as to permit development of all the land without fear of being inundated and destroyed by floods as has been the experience in the past. Each landowner will need to provide his own internal water control and we should expect to see the very best plans prepared and executed. We now have much better technoligical information on how to treat each acre for its best use than ever before. We now need to apply this information gained from experimentation and experience in such a way that this area will become a landmark to the agricultural scientists who have assisted with its development.

Although we have assembled a great deal of technological data, there is still much more that is badly needed. This particularly includes weather data, both temperature and precipitation. A general soils map prepared by the Everglades Drainage District is available but covers only a portion of the area, and individual farms have soil maps prepared by the Soil Conservation Service.

Detailed soils maps are a necessity, however, for intelligent planning of crop rotations, fertilization, cultivation and water control. We also need considerably more physical and climatological information to determine proper factors for application to individual water control development plans. Among these are run-off, infiltration and percolation rates for the specific soils encountered.

DEVELOPMENT PROCEDURE

The Indian Prairie-Lake Istokpoga area presently is less than 5 percent developed. Large areas of land are ready for development and have great potentials for agricultural production. Most of the area is in the hands of large landowners and corporations. This usually indicates that large tracts will be developed at one time. It is necessary under such conditions for the development to follow a logical and efficient pro-

cedure since a large amount of money may be quickly expended under such conditions. Such a plan of work normally follows five steps.

1. Classification of soils.
2. Selection of crop or crops to be grown.
3. Provision of outlet and inlet facilities for water control.
4. Development of interior water control plans.
5. Development of field layout for water control.

Step No. 1—The classification of the soils should be made first since the soil is the basis for the entire operation. Thus soil borings made prior to constrcction of the Project canals influenced selection of the design data used to prepare the construction plans. It is imperative to know what soil is present before Step No. 2 can be determined. Soils vary considerably and in a great number of ways and each variation and combination of variations must be carefully considered in developing water control plans. Among these variations are: texture, —from fine clays to coarse sands, organic material, color, permeability and infiltration rate, elevation and slope of the land, erodability, fertility and whether acid, neutral or alkaline in reaction, and a great number of combinations of these differences.

Step No. 2—The determination of the crop or rotation of crops to be grown will influence the steps that follow since crops vary in fertility requirements, water tolerance, cold resistance, depth and breadth of root zone, tillage requirements, field operations, insect and disease susceptibility and many other agronomic factors.

Step No. 3—The outlets and inlets for water control are provided when the Project canals and structures are considered. Careful planning as to the manner of connecting to the Project culverts and spillways are essential to insure the safety of the facilities and their satisfactory operation. Promiscuous ditching and developing can readily over-burden the Project canals in whole or part and cause excess silting, gulleying and eroding to such an extent that the whole Project might soon become ineffective and inoperative.

Step No. 4—The development of the interior water control plan is based primarily on steps 1 and 2, the soil encountered and the crop to be grown, along with the many variables that must be considered in each.

Step No. 5—The development of a satisfactory field layout for which an operable water control plan has been planned and installed, should bring any particular area into readiness for cropping operations. If all aspects of the planning and installation have been carefully done the chances of a bountiful harvest are excellent. Otherwise almost anything can happen, including a complete and expensive failure.

Since farming has become a highly scientific enterprise it is essential that the more exacting phases of its development be planned by the technicans skilled in the various fields of agronomy, horticulture, agricultural economics, agricultural engineering and other professional agricultural sciences.

CONCLUSIONS

The benefits from the Project canals and structures are already abundantly obvious. As the entire area is developed these benefits will indeed reach a fabulous figure if the physical facilities are properly maintained

and operated. When this is done there will have been added to Florida's expanding agriculture a vast area of productive land made largely so by thoughtful and constructive effort.

RECOMMENDATIONS

The Corps of Engineers, U. S. Army and the Central and Southern Florida Flood Control District have gone to great expense to construct the Project canals and structures for this vast area. It is up to the residents and owners of the land to see to it that these structures are used properly and to best advantage and not misused or abused. To this end the best technological information available should be used in assisting the residents and owners with plans for the proper development of their land.

Administrative Practices in the Central and Southern Florida Flood Control District

G. E. DAIL, JR.[1]

INTRODUCTION

Many will recall that two hurricanes and their attendant damages amounting to more than $59 million in 1947 in central and southern Florida caused local interests to seek Federal aid to implement a Flood Control and Water Conservation Project.

A comprehensive report on examinations, surveys, and reports on rivers, lakes, and canals in the area resulted in acceptance by the Federal Government of responsibility for prosecution of a project for flood control and other purposes. The Project was authorized by the Congress of the United States in the Flood Control Act of 1948. At the meeting of the State Legislature in 1949, the Flood Control District was established and authorized to be the responsible local interest in the Project.

The 1949 legislative enactments provide the basis for the local interest divisions of cost. The State of Florida, through the General Revenue Fund, agreed to provide the matching funds for construction costs (initially 15%, later 20%.) and funds for water storage areas and public highway bridge improvements. The Flood Control District was authorized to levy up to one mill on real property district-wide to provide funds for the purchase of rights of way, to operate and maintain completed works and to discharge all other responsibilities of local interests.

Federal responsibility for the Project is vested in the United States Army Corps of Engineers. The Corps is both the planning and construction agency for the Project, which now has an estimated total cost of $333 million.

Thus, the relationship between the State of Florida and the Federal Government lies basically with the Flood Control District and the Corps of Engineers. Although prevented from operating at peak efficiency by

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Mr. G. E. Dail, Jr. was born in Philadelphia and was educated at the University of Pennsylvania and Stetson University where he received a Bachelors degree in Economics. He later completed a post-graduate course in Management and Political Science at Florida State University.

Prior to his appointment as Executive Director of the eighteen-county Central and Southern Florida Flood Control District in 1958, he served in several capacities with the University system of Florida, and as special assistant to the Governor. For nearly five years, he was assistant business manager with the Florida State Board of Control.

During World War II he served with the O. S. S. in the China-Burma-India Theatre of Operations, and returned to active duty with the Army Security Agency during the Korean conflict. He now holds the rank of captain in the Army Intelligence Reserve.

He is a member of the Sigma Nu fraternity, a Kiwanian, a member of the West Palm Beach Chamber of Commerce, and an active member of the Florida State Chamber of Commerce, for which he is on several committees.

the many legislative and administrative restraints and procedures at both the State and Federal level, it is doubtful that a better modus operandi could have been devised. As is usual in complex financing through government, funding deficiencies at one level or another constitute the greatest deterrent to orderly and efficient progress.

Work in the Project began in 1950. Logical construction stages required the erection of a main levee between the Everglades and the east coast area, initiation of levees to enclose the agricultural area south of Lake Okeechobee, and construction of pumping plants. Work in three conservation areas and improvement of Everglades Drainage District works, which became a part of the Project, was also essential if the following project purposes were to be achieved:

1. Remove flood waters rapidly.
2. Store surplus water.
3. Prevent overdrainage.
4. Prevent salt water intrusion.
5. Protect developed areas.
6. Permit additional urban and agricultural development.
7. Improve navigation.
8. Conserve fish and wildlife.
9. Recharge ground water.

The integrated system of reservoirs, channels, levees, pumps, spillways, control structures, and salt water barriers to accomplish these aims is only 22% complete but has already prevented more than \$50 million in flood damages. The Project now enjoys a benefit to cost ratio of 3.8 to 1.

If the Flood Control District is to fulfill the purpose summed up in the phrase "to be responsive to the needs of local interests" its administration must know and understand what those needs are and satisfy them. From the very beginning of this Project when the document setting forth its aims and goals was written, recognition was given to the dual roles which its rural and urban aspects demanded. For example, the document states that "Some parts of the plan, however, such as those required for protection of human life and of existing highly developed urban and agricultural areas are obviously more urgently needed than the longer-range features of the plan." In addition, engineering considerations required an order of development which would produce, step-by-step, construction of the works which could be operated from the beginning with the greatest efficiency, and which would obtain progressively the benefits which the plan was designated to produce.

The early priorities included construction of the main levee between the Everglades and the east coast to protect coastal communities from overland Everglades flows and building of levees to enclose the agricultural area south of Lake Okeechobee, the complementary pumping plants and local protection works in Palm Beach, Broward and Dade Counties. These works have been constructed with the result that flood damages prevented in agricultural areas alone have exceeded the cost of the works providing them.

The original Project document summarizes local cost-sharing requirements by stating that the flood protection, drainage, and water control features of the comprehensive development will operate jointly to produce large benefits attributable to increased or higher use both of agri-

cultural and urban property. The preponderance of such benefits from other sources indicated that substantial local cooperation was warranted.

INTERNAL ORGANIZATION OF THE DISTRICT

Chapter 378, Florida Statutes provides that the District shall be under the policy direction of a governing board of five members who shall be owners of real property in and shall reside in said District. Members to compose said Board shall be appointed by the Governor and confirmed by the State Senate. Not more than one member shall be appointed from the same county and said members shall serve staggered terms of three years each.

An executive appointed by and responsible to the Board administers District affairs. As its chief administrative officer he supervises line and staff functions.

The chief operating units are the Engineering and Operation and Maintenance Divisions, each headed by a staff director.

Other functions are represented by departments for land acquisition, finance, advance planning, and general services. Heads of these departments and divisions, along with the District's attorney, make up the staff which requires unusually close coordinate action to perform the diverse functions required of the entire agency in its relationship with other units of government and property owners.

APPLICATION OF ADMINISTRATIVE PROCEDURES

Good administrative practices require coordination of every level whether it be in planning works, acquiring lands and rights of way for works, or, of particular moment, operating and maintaining the completed works to the end that the Project benefits will be achieved and that local interests' needs will be served.

Because you are an agricultural group, it seems appropriate to emphasize to you the administrative practices of the Flood Control District with special reference to agricultural and rural applications. It must be understood that parallel activities maintain for other areas but these are not germane to this paper. It may be emphasized here that the Everglades Agricultural Area is a nearly completed unit of the Project and exemplifies the advantages and benefits which can be anticipated in as yet incomplete areas such as South Dade County, the Upper St. Johns River Basin and the Upper and Lower Kissimmee River Basin.

The comprehensive report on central and southern Florida for flood control and other purposes states that the area in question is "potentially rich and productive;" that "the areas form a single economic unit;" that "gravity drainage from some agricultural areas (was) not feasible;" and that during dry years "cattle died in the pastures . . . smoke from burning muck lands of the Everglades darkened the coastal cities and salt water moved inland along drainage canals and through the underlying rock as the supply of fresh water diminished." The report also states that the District Engineer, Corps of Engineers, the planning and construction agency in Federal flood control projects, has prepared a comprehensive plan to provide protection against a disaster such as the flood of 1947 by major drainage outlets, control structures, and water conservation

facilities which are needed "to stabilize the present agricultural economy."

The same document also found that analysis of the benefits and costs of the plan of improvements indicated that it is justified economically by a wide margin.

From the very beginning, then, the District has devised ways and means to bring about benefits to justify its existence and to meet the needs of agricultural and other interests equally.

HIGHLIGHTS OF ADMINISTRATIVE PRACTICES

District Permit Procedures

Basic Florida Statutes define the District's authority and responsibility to control water levels in canals, to augment works in the Federal Project, and to prescribe the manner in which secondary works connect with and make use of the works of the District, and to issue permits for such work,

Federal Statute limits civil works projects such as this one to providing primary works. Therefore, the individual on-the-land secondary and tertiary system and its functions are of paramount importance if the ultimate anticipated benefit of the Project is to be realized.

The policy of the District in considering and issuing permits prevents works which will interfere with District activities or be inconsistent with its overall functions.

The permit procedures have benefited agriculture in several ways. Individuals have received guidance and counsel in relating their own irrigation and drainage problems to the primary purposes served by the District. A uniformity of cooperation has been achieved which has protected the farsighted farm operator from unregulated and irregular neighboring practices. The fact that the District regulates discharges into, or withdrawals from, District works affords a fair distribution of service to all.

The District as successor to the Everglades Drainage District has been able to make available through permit procedures rights-of-way which might otherwise have been lost to the public domain. This administrative procedure derives from canal reservations granted to the Everglades Drainage District for the furtherance of its operation. Agricultural areas have been, or will be, the chief beneficiaries.

The existence of the District has made possible the prevention of $51.5 million in flood damages from 1953 to date in the agricultural areas alone. The administration of the works to do this job is the subject of another paper; however, the figure alone reveals the extent of the Project's ability to serve agriculture beneficially in spite of its incomplete state.

The District Budget

District presentations of data before Congressional public works flood control committees and appropriations committees have resulted in authorizations of $106,300,000 to the Project and appropriation of nearly $69 million to date.

The Flood Control District will request the Legislature to appropriate $13,450,080 as the State's contribution toward construction of $49,851,600 worth of work in central and southern Florida, for the purpose of water storage lands required before work can begin in the Upper St. Johns Basin, for bridge relocations, and repayment of District advance.

The State's appropriation in past biennia to the District have totaled \$19,023,000. Of this amount \$16,490,724 has been released. The 18 counties in the Flood Control District have provided more than \$21 million in ad valorem taxes to purchase lands, easements, rights-of-way and maintain and operate completed Project work. The Federal Government has authorized expenditures to date of more than \$106 million in the Project and has appropriated \$68,692,000 to pay the Federal share of 80% and 85% respectively of the construction cost of Project works depending upon their time of authorization.

The State of Florida is profiting in increased tax revenues collected in central and southern Florida for the reason that the protection afforded by the Project and its various water control and conservation benefits have attracted a population which has doubled in 10 years.

Appropriations to the Project represent an investment of between 15% and 20% in a project on which the Federal government furnishes the remaining 85% and 80% of funds needed to construct it. By investing \$1.00 now the State will reap a fourfold advantage within the foreseeable future.

Cooperation with Counties and County Committees

The District has cooperated with county flood control and water conservation committees and other local groups. Such mutual cooperation has contributed greatly to the refinement of the basic Project plan and made it more responsive to local needs. The administration of final programs for given areas can only succeed when the individuals involved know and understand their own problems in the frame of reference of the District-wide program. By having liaison at the county level, the Flood Control District has been able to better appreciate and resolve differences. The most recent example of such a procedure is in the Upper St. Johns River Valley where several plans of water control have been discussed and a plan acceptable to the people involved has been worked out. The recently completed *Report on Flood Conditions in the Flood Control District* is an excellent example of cooperation among municipal officials, county agricultural agents, civil defense agencies and interested individuals.

Public Information

Similar administrative procedure is exemplified in the public information and education program. Based on the principle of making the Project, its works and its purposes known to as great a number of taxpayers and potential taxpayers as possible, the effort has shown good results. Exhibits at fairs and expositions, news releases circularized to representative daily and weekly papers, and addresses and film showings to civic and cultural groups have diffused knowledge of the Project.

Cooperation With Other Agencies

The District affords the opportunity for administration of cooperative programs with Federal and State agencies in addition to the more local cooperation previously mentioned. Many fields in soil and water conservation research and aquatic weed control have been explored by District support afforded the Agricultural Research Service, Soil and Water Conservation Research Division, and Crops Research Division. A cooperative agreement for investigation of water resources with the U. S.

Geological Survey collects basic stage data in the Upper Kissimmee Basin and St. John area essential to maintain continuous records for District use in determining future operation schedules. Another data collection program in which the District and the Geological Survey cooperate is drainage basin studies on areas of varying size to trace the amount of rainfall that separates into surface water runoff, evapotranspiration and seepage. Basins studied are the Indian River Farms Drainage District, the Taylor Creek Basin, and the Monreue Ranch Watershed. These basin studies are on a long term basis so that information may be obtained on effects on the hydrologic cycle as native areas are improved to provide a measurement to determine ultimate design criteria.

Status of the Entire Project

For purposes of this paper, special attention has been given to agricultural areas in the Project. Here, fuller data is given on the Project as a whole.

The Flood Control Act of 1960 provided authorization of an additional $23 million to this Project. With the funds remaining, there are $37½ million in Federal authorizations available for appropriation as of the beginning of the fiscal year 1962.

The federal budget for fiscal year 1961 recognized the necessity for continuing and completing works under construction in the four major Project areas and initiating other vitally essential works. In addition, as a result of an inspection of the Dade County area by the Chief of Engineers, recommendations for emergency work there were made to the committees on appropriation. These recommendations by the Corps of Engineers and local interests resulted in a substantial increase in the sum appropriated for fiscal year 1961.

At its inception in 1949, the Project was expected to be completed by 1965. At the present time, the Project is approximately 20% complete. It is appropriate here to repeat a frequently made statement that the Project has already prevented flood damages in amounts in excess of Project costs. For example, the June 1959 flood resulted in about $400,000 damages in the Lake Okeechobee-Everglades area and in the east coast area. Without the Project works, damages would have amounted to $12 million. Structures and other flood prevention works in this area cost approximately $7.5 million.

Work is only beginning in District areas where hurricane Donna caused considerable damage. These areas are the Kissimmee and Caloosahatchee River Basins, the northwest shore area of Lake Okeechobee, and south Dade County. It is essential to initiate and/or continue these works at an accelerated rate and to start additional works in south Dade County to minimize the potential damage from recurring storms. It is noteworthy that the South Dade Snapper Creek Canal area (C-2) suffered less damage than similar areas due to the ability of that Project work to accommodate flood discharges.

EAST COAST-EVERGLADES AREAS

Funds already provided have initiated, continued, and/or completed essential elements of the Project for relief from flooding of the populous areas of the lower east coast where, according to the 1960 census, the population has doubled during the past 10 years.

Conservation Area No. 2 was the scene of activity during the year with

work in progress on the interior levee (35B) which is expected to be completed in July, 1961.

Work on Section 1 of Black Creek (C-1), in Dade County, is expected to be complete in the fall of 1961, as is Biscayne Canal (C-8).

LAKE OKEECHOBEE-EVERGLADES AREA

Pumping Station S-8 is under construction and is expected to be complete in the fall of 1961. It is the remaining pumping station on the perimeter of the Agricultural Area and will serve the western section tributary to the Miami Canal. Channel excavation and one major structure in the Caloosahatchee River is scheduled to begin this year to provide substantial additional discharge capacity for Lake Okeechobee. Concurrently, work is being initiated to surround the Lake with perimeter levees to provide greater protection of life and property and increase storage. Accelerating construction on these works is essential to control of the Lake.

KISSIMMEE RIVER BASIN AND RELATED AREAS

For the first time water control works were brought to this area. The Slough Ditch Canal (C-41A) will be completed in the fall of 1961. Meanwhile, work on State Road No. 70 Ditch (C-39A), Indian Prairie Canal (C-40), and Harney Pond Canal (C-41) will be completed during Fiscal Year 1961 to afford essential protection to pasture lands and to provide some measure of regulation for Lake Istokpoga. This will result in considerable progress toward establishment of adequate water control in the area.

Studies initiated by the FCD, investigating the feasibility of constructing outlet canals and structures in the Upper Kissimmee Lakes Area prior to completion of the Kissimmee River improvements, have been forwarded to the Corps of Engineers for their consideration. This District considers the construction of improvements in that section as an emergency need to afford interim protection to highly developed and rapidly growing urban and industrial areas. The lake stages and streamflows in this Upper Kissimmee Basin have threatened the surrounding towns for a year and a half and are now at an all-time record high level.

UPPER ST. JOHNS RIVER BASIN AND RELATED AREAS

Protection and water control for the greater portion of St. Lucie County is in prospect with the completion of a section of Canal 24 and Structure 19, and the completion during calendar 1961 of Canal 25 with Structures 50 and 99. Canal 23 and Structures 18 and 97, serving portions of Martin, St. Lucie, and Okeechobee Counties, is scheduled to begin this year for completion in 1963.

Present Corps of Engineers' planning for the Upper St. Johns River was not responsive to the needs of local interests. It appeared to be too costly to be accomplished in the foreseeable future. Consequently, the Flood Control District has recommended an alternative plan which embraces the same principles at a lesser cost.

This plan is currently under study by the Corps of Engineers. An early resolution of the St. Johns problem is essential to provide the following benefits: a dependable domestic water supply for a major part of the coastal area; a reasonably dependable irrigation water supply; disposal and control of excess flood waters for improved agricultural use of St. Johns River Valley lands; and preservation of rapidly diminishing fish, wildlife, and recreational values.

CONCLUSION

Administrative practices in the Flood Control District correlate the Project purposes to the end that they may fulfill the water control and related needs of central and southern Florida. It has been shown that the procedures of administration are equally divided among planning, financing and construction, on the one hand, and, no the other, the manipulation of the completed works, the cooperation with other agencies, and the reconciliation of the available means to the appropriate Project ends.

Operation and Maintenance of the Completed Works of the Everglades Agricultural Area

Z. C. GRANT[1]

DESCRIPTION OF AREA

The Everglades Agricultural Area is located adjacent to the south shore of Lake Okeechobee. It is approximately 30 miles in width and extends 25 miles southward. The area is bounded on the north by Lake Okeechobee; on the east by the Hungryland Slough and Conservation Areas Number 1 and Number 2; on the south by Conservation Area Number 3; and on the west by Hendry County. (See Figure 1, p. 283).

The Agricultural Area contains 1130 square miles (723,000 acres) of land, or approximately 25% of the total Everglades. The land is low in elevation and extremely flat. It varies generally in elevation from 16 feet mean sea level to 12 feet mean sea level with average near 13 feet mean sea level.

The soils of the Area are almost all suitable for extensive agricultural usage. The general types of soil are Okeechobee muck and Okeelanta peaty muck, which are found in the area around the south and easterly shores of Lake Okeechobee; mucky sand lands including various mixtures of muck with Palm Beach, Davie, Pompano, Immokalee and Leon fine sands which are found in an area lying southwesterly of the Lake; peaty muck in the remainder of the area (1).

The climate of the Everglades is similar to that of the tropics or subtropics. The temperatures are mild throughout the year with very little variation between the extreme and average temperature. The maximum temperature is approximately 100 dgrees F. and the minimum about 24 degrees F. Average annual temperature is approximately 72.2 degrees F. Frost can occur in the Area for a day or two at a time from November through March with January being the coldest month. The proximity of the land to Lake Okeechobee seems to have an effect on the degree and severity of frost damage.

The closer the land to the lake, the less the frost damage. The humidity is quite high in this section of Florida, averaging about 88% at midnight and 62% at midday.

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Mr. Grant was born in West Palm Beach, Florida, November 4, 1928. He received his Bachelor of Civil Engineering degree from the University of Florida in 1950.

He served in the U. S. Army from December, 1950 to December, 1952. He was attached to the Post Engineer's Office at Benecia Arsenal, Benecia, California where he was engaged in engineering design work. He was employed by the Central and Southern Florida Flood Control District in January, 1953 and in 1960 became the Director of the Operation and Maintenance Division.

He is a member of the American Society of Civil Engineers and of Sigma Tau (Honorary Engineering Fraternity).

He is a registered professional engineer in the State of Florida.

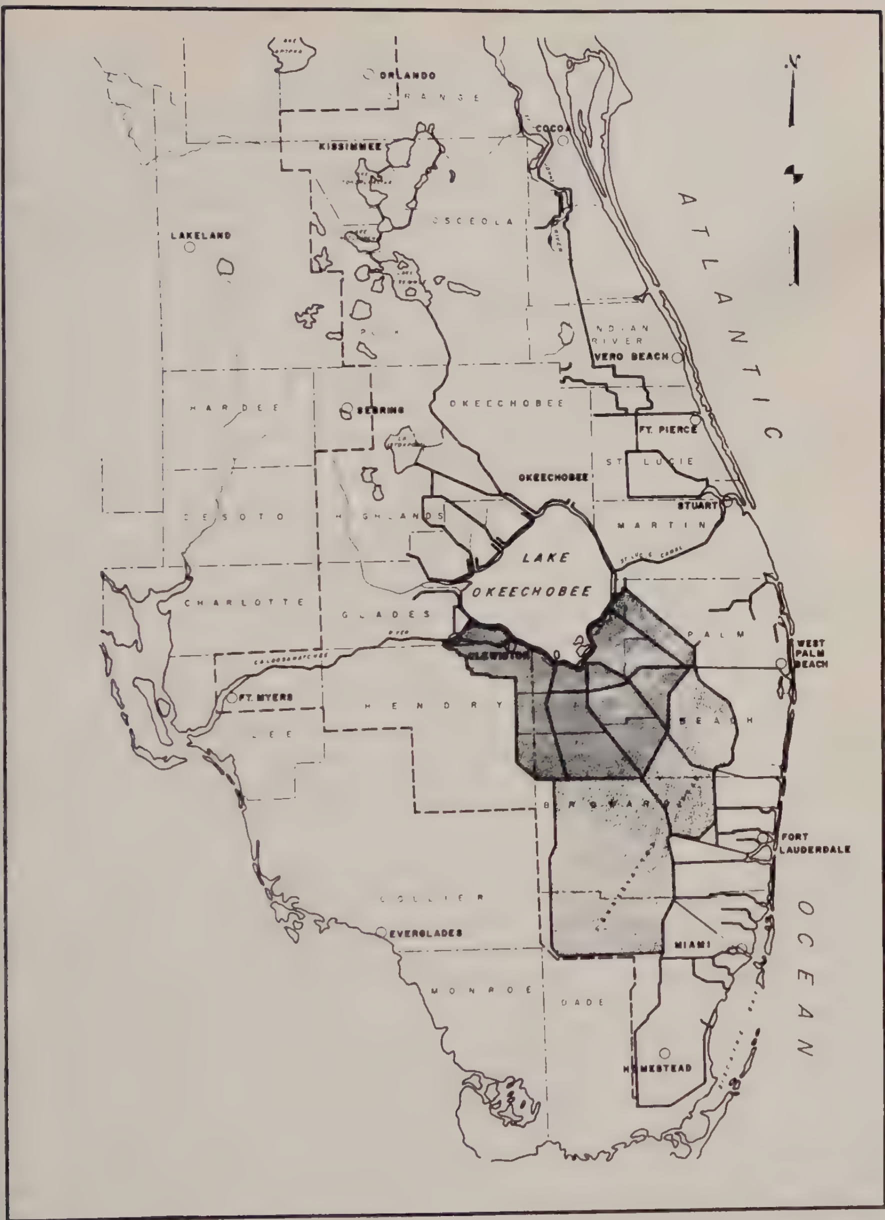

Fig. 1.—General location map of Central and Southern Florida Flood Control District showing "Agricultural Area" and Water Conservation or "Overflow Area."

The remaining important climatical feature is the rainfall. The normal annual rainfall is 55.39 inches. It is important to note that better than 76% of this falls in the six month period from May through October. The extremes in rainfall which can be experienced in the Area from year

to year are best exemplified by the maximum and minimum for the period of record which are as follows: Maximum Year 1947, rainfall 81.41 inches—Minimum Year 1956, rainfall 37.23 inches.

The location, type of soil and climate make the Area highly desirable for agricultural development and portions of it have been under cultivation since the early part of this century.

The Everglades Agricultural Area now has approximately 35% of its 1130 square miles in use for agricultural purposes. In 1959-60 farming season this Area had in production the acreages shown on the following table:

TABLE 1.—LAND USE IN THE EVERGLADES AGRICULTURAL AREA IN 1959-60 FARMING SEASON

Land Use	Acres
Beef Cattle Production	137,600
Truck Farming	60,200
Sugar Cane	55,000
Ramie and Other Crops	1,000
	253,800

The farming industry of the Everglades Agricultural Area today has an annual crop production valued at Seventy Million Dollars.

PROJECT DEVELOPMENT

It had been recognized early that in order to make use of this vast area of rich agricultural land the Lake must be controlled. The first attempts to drain this Area date back before the turn of the century. It was at this time that the first channel outlet from Lake Okeechobee was dug. The purpose of the canal was to control the Lake and connect it with the head waters of the Caloosahatchee River. Prior to this the only Lake control came from natural overflow to the south Lake rim into the Everglades.

As more development justified it, construction of other major drainage outlets were dug between 1906 and 1929 to help control Lake Okeechobee and drain the Everglades. These are shown in Table No. 2 as follows:

TABLE 2.—CONSTRUCTION DATES FOR EVERGLADES DRAINAGE DISTRICT CANALS

Canal	Construction Date
Miami	1906-1929
North New River	1906-1929
Hillsboro	1913-1929
West Palm Beach	1913-1929
Caloosahatchee	1884, 1906-1929
St. Lucie	1916-1928

As experience was gained in the operation of this system of canals by the Everglades Drainage District, it became apparent that there was still much to be done if adequate water control was to be obtained in the Everglades. The disastrous hurricanes of 1926 and 1928 drowned thousands in this Area and led to the construction of the present Lake

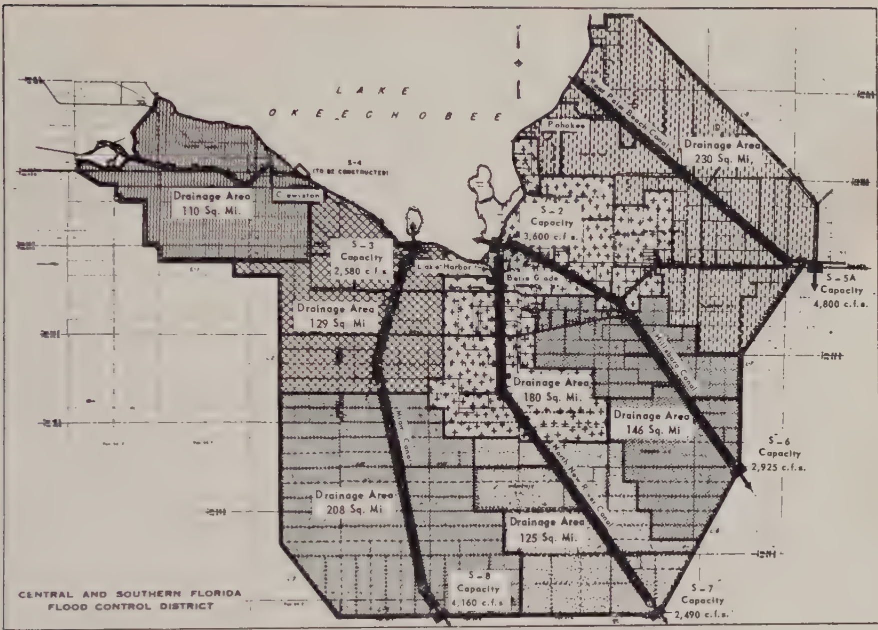

Fig. 2.—Detail of Agricultural Area as shown on location map of Fig. 1.

levees on the south and north rims of the Lake by the U. S. Corps of Engineers. However, it was not until after the severe flooding of this Area and all south Florida in the fall of 1947 that a Project plan was devised. A plan that was to be constructed by the State of Florida and the Federal Government.

The Central and Southern Florida Flood Control District was created by the State Legislature in 1949 with one of its primary purposes being the operation and maintenance of the complete works of this Project.

The Project plan for the Everglades Agricultural Area incorporated an adequate flood protection system with water storage and conservation. Proper utilization of the water resources in the Area would produce tremendous benefits from:

(1) Irrigation water for agricultural areas.
(2) Improved ground water control.
(3) Improvement and replenishment of east coast well fields and streams for water supply.
(4) Salinity control for east and west areas.
(5) Recreational facilities on Lake Okeechobee and related waterways.
(6) Increased navigation depths in Lake Okeechobee and related waterways.
(7) Conservation of the peat and muck lands of the Agricultural Area.
(8) Conditions favorable for propagation of fish and wildlife in Lake Okeechobee, the Conservation Areas and Everglades National Park.

To accomplish the aims as set forth above, a plan of improvement for the Everglades was designed which is basically as follows:

(1) The usable muck lands of the Area were to be enclosed in a perimeter dike to protect the Area from the inflow of water from the land around it.
(2) Enlarge each of the major existing canals in the Area to remove a design flow of 3/4 inch of water off the Area in 24 hours.
(3) Construct pumping stations on each of these canals to pump this design flow either into Lake Okeechobee or the Conservation Areas for storage and future utilization. (See Figure 2. p. 285).

Construction of the perimeter dikes (which are numbered 1 through 8 on the map) was started in 1951 with the construction of L-8 and completed in 1957 with the completion of L-6.

The pumping stations which protect the Area are as follows: S-2, S-3, S-4, S-5A, S-6, S-7 and S-8. All of which are complete except S-8 which is now under construction, and S-4 which is projected for the future.

The enlargement of the West Palm Beach Canal (L-10 and L-12), Hillsboro Canal (L-14 and L-15), North New River Canal (L-18, 19 and 20) and Miami Canal (L-23, 24 and 25) have been completed. All of these works have been turned over to the Flood Control District for operation and maintenance.

The cost of construction of these works of the Everglades Agricultural Area was $30,558,693.54.

OPERATION AND MAINTENANCE

The responsibility for the operation and maintenance of the completed works of this Project lies with the Central and Southern Florida Flood Control District. The monies necessary to accomplish this are derived from an ad valorum tax (Maximum 1 mill) levied by the Governing Board of the District upon the land in the 18 county District.

The U. S. Corps of Engineers has established the criteria under which the Project is to be operated. These criteria were agreed upon by both agencies, the Government and the Flood Control District, after long and thorough engineering studies were made.

The Project has established an elevation of 13 feet mean sea level as the desirable irrigation stage for the entire Agricultural Area.

The design runoff for storm conditions is 3/4 of an inch of water in 24 hours from the entire Area. This is accomplished by pumping at the several pumping stations in the Area. The pertinent design data is the following table:

Pumping of the canals is required when the stage at the upper end of the drainage area exceeds 13.0 feet mean sea level. The amount of pumping required is that necessary to keep the canal at 13.0 feet. This is, of course, limited by the total design capacity of the pumping station.

When the stage in the canals of the Agricultural Area falls below 13.0 feet mean sea level during the irrigation season, releases are made from Lake Okeechobee by gravity to restore them to the desired elevation again.

The foregoing are the design operational requirements for the Everglades Agricultural Area. Certain features were incorporated in the

TABLE 3.—DESIGN CHARACTERISTICS OF EVERGLADES AREA PUMPING STATIONS

Pumping Station	Drainage Area Square Miles	No. of Pumps	Total Capacity C.F.S.	Design Water Surface in Feet Mean Sea Level	
				At Station	Upper End Canal
2	180	4	3,600	11.50	13.30
3	129	3	2,580	12.40	14.30
5A	230	6	4,800	8.30	13.60
6	146	3	2,925	10.00	13.30
7	125	3	2,490	10.80	12.20
8	208	4	4,160	12.00	14.30

design of the pumping stations and canal systems to help insure the most reliable and economical operation. All pumping stations are designed as self-sustained units which operate by diesel fuel and have electric generators to supply all needed electric power. This prevents any interruption of operation due to outside power failures.

All stations are designed with three or more pumps to get the total required capacity. This feature insures a flexibility of operation for pumping of storms less than design and insures that a breakdown of a pumping unit will not stop operations and will cut capacity by no more than one-third.

A supply of spare parts for the engines and pumps are kept at each station to help insure a minimum of down time for replacement and repair.

All canals in the Area have a minimum design depth of 10 feet. This feature helps impede the growth of submerged aquatics in the canal, as well as the extension of bank growth such as paragrass and willows into the canal to the extent that they seriously affect the flow of water.

The canals are also designed with a required mound or dike on each side. Water enters the canal by culverts through these dikes. They serve three purposes:

(1) To limit the inflow by culvert size to that for which the system is designed.
(2) To control the location of inflow and protect the canal from erosion and damage from uncontrolled overland inflow.
(3) Provides a means of access for proper maintenance of the canal.

There are other features of the design, too numerous to enumerate, which are of the same nature as those outlined above; incorporated to aid in proper operation and maintenance.

The District is now responsible for the maintenance and operation of 268 miles of levees, 204 miles of canals and 5 pumping stations in the Everglades Agricultural Area.

The personnel of the Operation and Maintenance Division are responsible for these works. The division is divided into two main sections: the pumping station section and field operations section. In the Agricultural Area there are 33 personnel who operate and maintain the pumping stations. These are sufficient to operate all stations on a 24 hour 7 day week basis. There are 22 field operation personnel working in the Ever-

glades Area on the canals, levees and structures other than pumping stations. Together, these 55 men are responsible for the operation and maintenance of all the Project in the Everglades.

The maintenance and operation of the pumping stations is an expensive undertaking. The 5 completed stations of the Agricultural Area have cost the District a total of $1,021,400.26 to maintain and operate up to June, 1960.

The operation and maintenance of the pumping station equipment is carefully planned and executed. All operating personnel have been carefully trained in the proper operation of the main engines and pumps and all auxiliary equipment at their particular stations. While the pumps are in operation all of this equipment is constantly watched, and gauges read and recorded to keep an accurate record of hours of operation and watch for possible breakdown.

Preventive maintenance on the equipment, such as greasing, oil changes, bearing checks, filter changes, gear checks, etc. are carried out in compliance with the recommendations of the manufacturer. All fuels and lubrications are approved by the equipment manufacturer, the Corps of Engineers and the Flood Control District before they are used. The engines and pumps at each station are thoroughly inspected, checked, repaired and adjusted before the start of each rainy season. As stated before, all stations carry a large complement of spare parts. All of these things are done to insure as much as humanly possible the continued operation of all our pumps without breakdown.

The 472 miles of canals and levees must also be maintained to be able to insure their satisfactory operation. This is the responsibility of the field personnel. The dikes must be mowed and chopped to control the wild growth on them such as willow, paragrass and maidencane. If this was not done, travel over them would soon be impossible. The levees must also be maintained at a required design elevation at all times to prevent a breaching or overlapping. It is important that this elevation be checked periodically because of the tendency of the muck land under them to subside. The levees were built two feet above the required design height to help offset this subsidence.

Culverts are also checked periodically to insure their proper operation. All culverts in the Agricultural Area are equipped with risers or headers on them to allow the placing of boards in them to control the water on the land.

The Flood Control District has made a practice of placing boards in the culverts which serve undeveloped lands. This serves three purposes:

(1) Reduces the amount of pumping necessary to aid the developed areas.
(2) Helps prevent oxidation of the peat soils by keeping water on them.
(3) Helps prevent muck fires which destroy usable land.

The remaining major responsibility of the field personnel in the Agricultural Area is aquatic weed control. Control of aquatic weeds is one of the largest single items of expense we have in our canal maintenance. We have an aquatic weed program in the Flood Control District which has cost the Flood Control District approximately $190,000 in the

Everglades thus far. Chemicals for eradication alone cost the District $27,756.00 last year.

The common aquatics found in the Project canals are: Water hyacinths (Eichornia crassipes), Water lettuce (Pistia stratiotes), Duck weeds (Lemna spp.), Coontail (Ceratophyllum demersum), Para grass (Panicum purpurascens), Maidencane (Panicum hemitomon) and Alligator weed (Achyranthes philoxeroides). There are many other types of aquatics found in the Everglades Area but these are the ones which are most common to the Project canals and cause the greatest problems in control and eradication.

The District makes use of both mechanical and chemical means in their efforts to control these aquatics. The floating aquatics, hyacinths and water lettuce, are controlled by spraying a mixture of the herbicide, 2, 4-D, which is a contact killer, and water on the plants. Sticking agents are sometimes used to keep the chemicals on the leaves of the plant. The 2, 4-D is quite effective with these types of aquatics. A complete eradication of them in our canals could probably be affected if it were not for the continued reinfestation from outside untreated areas adjacent to the canals.

The other "floater" mentioned was duck weed. This plant causes no problem to water movement in the canal. It did create a serious problem at the pumping stations by clogging the strainers in the raw water intake for the engine cooling systems, causing overheating and eventual shut down of the pumps. Expensive, mechanical, self-cleaning, revolving screens were installed on the intakes which have eliminated this problem. No control program is being carried out against the duck weed. The submerged aquatics (Naiad and Coontail) do not as yet present any problem in the Everglades Agricultural Area. This is true primarily for two reasons:

(1) The canals of this Area have all just been recently enlarged, which destroyed the existing growth.
(2) The canals, for the most part, are deep enough to prevent sunlight from reaching the bottom and thus inhibit growth.

These aquatics, however, are a serious problem in other areas and will slowly reestablish themselves in the Everglades canals.

We are now cooperating financially with the United States Department of Agriculture, Agricultural Research Service, at their Florida Experimental Station in Fort Lauderdale, in a study to find a more effective, less expensive, safer chemical means of control for these weeds.

The "emerged aquatics", alligator weed, para grass and maidencane are ones which present a different type of problem. The alligator weed poses the most serious problem of the three. Early efforts to control this weed with 2, 4-D were ineffective. However, a formula for a mixture of 2, 4-D, aquaherb and water, developed by the Agricultural Research Service, has proven more effective. Studies are continued to develop better chemical treatment.

Para grass and maidencane are controlled by mechanical means. On the levees and canal berms mowing and chopping has been found to be the least expensive means. In the areas where the grasses are partially submerged and mowing is impossible, Dalapon is used to kill the weed. This is an extremely expensive operation. We have not been able to

justify the use of soil sterilants in our work because of the expense of the chemicals.

One of the prime considerations of a properly operated system is the weather. Correct and up to date weather forecasts are an absolute necessity to proper operation. Daily checks are made with the Weather Bureau to obtain this information and make any preparations or operational changes necessary to meet an anticipated condition. The Miami office of the United States Weather Bureau has a radar unit in operation which can pick up any heavy rainfall and weather fronts or hurricanes, and can accurately plot their direction of movement and rainfall intensity. They always call our office and relay this information for any rain in excess of 2 inches.

To give us a more complete picture we also have placed rain gauges over the entire Area. The observers are instructed to call us anytime a rainfall of 2 inches in 24 hours is exceeded. With this weather information at hand we are better able to be prepared for heavy rains by starting our pumping earlier, and in some cases, before a rainfall occurs. We have found that lowering the canal stages prior to the heavy rains helps prevent flood damage from excessive canal stages.

Hurricanes offer a special problem to the District, not only in the Everglades Agricultural Area, but through the entire 18 county area. So much so, that a special hurricane procedure has been adopted by the District which outlines the responsibilities of all personnel. Everyone has been thoroughly versed on what he is to do. This saves time, confusion and mistakes when a hurricane is approaching. The progress of a storm is watched very closely, and based on the reports, forecasts and our experience, a hurricane alert sounded by the Director of Operation and Maintenance when deemed necessary. When this hurricane alert is given, the following action is taken in the Everglades Agriculture Area:

(1) All hurricane gates at Lake Okeechobee are closed to prevent inflow from it into the Agriculture Area.
(2) All pumping personnel report to their respective stations to remain there until the emergency has passed.
(3) All pump stations are immediately put in operation to pull down the canal stages to create more storage in advance of the storm.
(4) Additional outside personnel are put at the stations to help handle trash and any other emergency which might arise.
(5) Food is supplied to all stations for the men housed there.
(6) Additional field personnel and equipment are ready at our field office in West Palm Beach to handle any emergency that may arise in the canals or on the levees.

Communications is another important factor in proper operation of the system. Many of the pumping stations are in locations which are isolated—miles from the nearest commercial power or telephone. Vehicular travel is slow and inadequate as a means of communication. The only answer was the installation of a two-way radio communication system for the entire Flood Control District which would be adequate to keep in contact with all stations and mobile radio units. For the Everglades Area, a 250 watt base station was established at Station 5A (see map) and 60 watt units were placed at all stations and at the administration office West Palm Beach. The vehicles of key operation and maintenance per-

sonnel are equipped with mobile radio units and are in constant touch with headquarters.

All pumping stations report in to the base station every hour, giving water stages, operational data, rainfall and other pertinent data. The communications system and towers are designed to withstand most hurricanes and continue to operate throughout an emergency. Periodic preventative checks of the equipment are made to help insure dependable and continuous service.

BENEFITS

The Central and Southern Florida Flood Control Project has spent $31,972,259.09 in construction, operation and maintenance of the facilities in the Everglades Agriculture Area. Although the entire Project in this area is not complete, substantial benefits have been obtained already. These benefits are from both flood prevention and proper water control. No studies of the completed works has been undertaken to accurately determine the control benefits accrued from the storage of water in the Conservation Areas and Lake Okeechobee. These benefits, although quite large, are so intangible as to be hard to accurately determine.

The benefits which are derived from flood prevention can be accurately computed. These heavy rainfalls which have hit the Everglades Area have been analyzed for benefits. I would like to briefly outline the findings of the reports:

The first example is the flood of January 21-22, 1957. During this storm, an area of 650 square miles in the Everglades Agricultural Area received 2 or more inches of rain within a maximum of 9.6 inches being recorded near Belle Glade. Pumping Stations 2 and 5A were put in operation and were able to reduce the flooding damages. To show how much, I would like to quote from a Corps of Engineers report on the storm:

> "6. PERFORMANCE OF THE CENTRAL AND SOUTHERN FLORIDA PROJECT (2)
>
> Project construction was only partially complete in the affected areas, but pump station 2 at Lake Okeechobee and pump station 5A at the north end of conservation area No. 1, together with part of the collateral levee and canal system, contributed greatly to reduction in flood damages. The completed portion of the agricultural area canal system provided delivery of floodwaters to the pump stations which removed water from the flooded tributary areas at an estimated maximum rate of 5,800 cubic feet a second, transferring about 12 billion gallons of much needed water into Lake Okeechobee and conservation area No. 1. Local flooding was materially alleviated and flood damages were greatly reduced in the Lake Okeechobee agricultural area."

TABLE 4.—ANALYSIS OF AGRICULTURAL DAMAGES RESULTING FROM FLOOD OF 21-22 JANUARY 1957*

Area	Actual Damages	Estimated Damages without existing Project works	Benefit from Project works
Lake Okeechobee-Everglades	$1,000,000	$8,500,000	$7,500,000

*TABLE 4.—As taken from literature cited (2).

The second example of the flood prevention benefits which have accrued from the Project is the analysis of the flood of December 1957—January 1958 by the Corps of Engineers.

On December 23-25 heavy rains fell on much of the Everglades Agricultural Area when up to 13 inches was reported. Abnormally heavy rains were experienced during the month of January 1958 also. The entire 1130 square miles of Everglades Agricultural Area received in excess of 10 inches of rain for the period 23 December 1957 to 31 January 1958. Almost two-thirds of the Area had in excess of 15 inches of rain with a maximum of 22.9 inches occurring at Pumping Station 5A.

As to the performance of the Project facilities, I quote the Corps of Engineers Report:

"6. PERFORMANCE OF THE CENTRAL AND SOUTHERN FLORIDA PROJECT (3)

> Project works authorized for flood control were only partially completed in the agricultural and conservation areas where the peak rains occurred during the December-January storm. However, completed Pumping Stations 2, 3, 5A and 6 prevented large flood damages since they removed floodwaters pumped into the primary canals from the developed areas and maintained desirable stages in the primary canals. On 24 December the four stations pumped at a rate of about 10,500 cubic feet a second, removing water from the agricultural area into Lake Okeechobee and Conservation Area No. 1. During the period 24 December to the end of January, Pumping Stations 2 and 3 pumped about 175,000 acre-feet of floodwaters into Lake Okeechobee and Stations 5A and 6 pumped a total of 325,000 acre-feet of water into Conservation Area No. 1 for a total removal from the agricultural area about 500,000 acre-feet (over 162 billion gallons) of water."

There were damages from freezing weather which occurred during the same period as the flood. These were recognized in the benefits which were obtained from the Project operation. Following is a Table from the Corps of Engineers report which summarizes the results of their study of damages and benefits:

TABLE 5.—1957-58 FLOOD DAMAGES AND BENEFITS EXISTING LAND USE LAKE OKEECHOBEE AND EAST COAST-EVERGLADES CENTRAL AND SOUTHERN FLORIDA*

Area	Condition of Crops	Flood Damages Without Existing Project	Flood Damages With Existing Project	Benefits
Lake Okeechobee Everglades	Assuming freeze damage	$9,140,000	$300,000	$8,840,00
Lake Okeechobee Everglades	Not assuming freeze damage	12,260,000	650,000	11,610,000

*TABLE 5.—As taken from literature cited (3).

The third and final example of benefits is the storm of September 1960. The 1130 square miles of the Agrirultural Area had an average of 16 inches of rain for the month of September, with a maximum of 24.47 inches received at Pumping Station 6.

The Project pumping stations of the Area, 2, 3, 5A and 6 and 7 pumped 622,010 acre-feet (202,827,780,000 gallons) of water into the Conservation Areas and Lake Okeechobee during this period. It has been estimated that this pumping prevented flood damages in the Area in the amount of $7,200,000.

CONCLUSION

As we can see from the above examples, benefits are already being obtained from the Project. You will also note that there are still flood damages occurring in the Area. The Project is not intended to prevent all damage from flood but is built to reduce the frequency and severity of flooding to the point where economical utilization of the land for agricultural purposes can be obtained.

It also should be noted that in some isolated cases areas have been adversely affected by the Project. In a Project of the scope and magnitude of this one such things are bound to happen. A good example of this is the effect on the lands immediately adjacent to the Conservation Areas which have increased seepage onto their land from high water stages behind the dike. These same lands are also receiving flood protection and irrigation benefits from this same water storage.

A close study and analysis of the Project can lead to but one conclusion. The Central and Southern Florida Flood Control Project for the Everglades Agricultural Area, although not yet complete, is producing substantial benefits to the Area from flood prevention and proper water control and utilization.

LITERATURE CITED

1. Definite Project Report, Appendix I Hydrology and Hydraulics, Part I Agricultural and Conservation Areas and Lake Okeechobee and Its Principal Outlets. April 10, 1951.
2. Report on Flood of 21-22 January 1957 by Corps of Engineers, United States Army Office of the District Engineer, Jacksonville, Fla., May 1957.
3. Report on Flood of December 1957-January 1958, United States Army Engineer District, Jacksonville, Office of the District Engineer, Corps of Engineers, Jacksonville, Fla. August 1958.

SYMPOSIUM: LIMITING FACTORS IN FIELD CROP PRODUCTION UNDER FLORIDA CONDITIONS

Nathan Gammon, Jr., Presiding

Varietal Factors which Limit Field Crop Production in Florida

E. S. HORNER[1]

Field crop production in Florida seldom reaches the high level we desire because of various factors which limit the potential at one stage or another. Many of these limiting factors, such as disease susceptibility or poor adaptation to the local environment, can often be eliminated by breeding improved varieties. In fact, it can be said in general that all plant breeding projects have the primary objective of overcoming limiting factors. The problems vary from crop to crop, as will be shown later, but it is important to point out that the productivity of any variety is the result of complex interactions between heredity and environment occurring over the growth cycle. Most of the crop species now cultivated in Florida have been introduced from other parts of the world where different environmental conditions have prevailed. Because of this, and because Florida's climate is conducive to multiplication of insects and diseases, the plant breeder's job here is particularly complicated. Many crops commonly grown in the North can be grown in Florida only with difficulty, if at all.

The purpose of this paper is to point out the limitations of some of the crop varieties that are either important or potentially important to the agriculture of Florida, and to discuss the role of plant breeding in overcoming these limiting factors. First some examples of successful breeding projects will be mentioned, and then the important crops will be discussed in order to bring out some of the problems now facing us.

PREVIOUS ACCOMPLISHMENTS

There are many examples of limiting factors in crop production that could be cited which have been overcome by plant breeding. Probably the best known in Florida is the breeding of a variety of shade tobacco resistant to black shank, which had threatened to wipe out that industry in Florida (5). Other examples include development of high quality peanut varieties (2), which permitted production in Florida for the edible peanut market; new oat varieties, resistant to crown rust (3), which have permitted continued economical production of oats in the state; high yielding soybean varieties adapted to the day lengths of Florida (4), resulting in economical production of that crop; sugarcane varieties resistant to cold, red rot and mosaic and with high sugar content (1), which have made this crop commercially feasible on the organic soils in the Everglades; and hybrid corn, which has overcome a physiological barrier by providing more vigorous plants capable of producing 25 to 40 percent more grain per acre than the best open pollinated varieties. These are only a few examples

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which illustrate the importance of plant breeding to field crop production in Florida.

PRESENT PROBLEMS

Although much has been done to improve the performance of field crop varieties by plant breeding, many faults still exist. In general, the most important single factor which limits crop production in Florida is disease; fortunately, it is feasible to breed for resistance in nearly all cases because sources of resistance usually can be found somewhere in the world. Other factors which either limit production or limit the value of the harvested crop are susceptibility to drought, lodging, and insect attack; poor quality or chemical composition; and lack of adaptation to local environmental conditions. In addition to such specific factors, it is likely that none of the improved varieties now in use approaches the ultimate maximum with respect to overall yield potential under present environmental conditions. As the fertility of the soil is improved and irrigation becomes more common, it will be necessary to develop varieties which can better utilize optimum soil conditions if maximum production is to be obtained.

Field crops in Florida can be divided into two general categories concerning limiting factors in their production: (1) those in which reasonably "well-adapted" varieties have been developed and with which satisfactory production can be expected year after year; and (2) those in which available varieties are "poorly adapted" in the state.

In the group of crops with well-adapted varieties, we might place corn, peanuts, pasture grasses, sugarcane, tobacco, oats, rye, soybeans, and white clover. These crops can be grown in certain areas of the state with reasonable assurance of success if proper cultural practices are followed. In other words, there are no critical limiting factors operating which make growing improved varieties of these crops difficult in the areas to which they are adapted. However, these varieties still have faults that can be corrected by breeding.

In the group of crops poorly adapted to any region of the state are lupines, alfalfa, red clover, crotalaria, sorghum, wheat, barley, and many others. Before these crops can be grown profitably in Florida, a major breeding job must be completed.

The main limiting factors that appear to be capable of improvement by plant breeding in these crops are discussed briefly below.

Adapted Crops

Some of the more important limiting factors in the adapted group of crops are listed in Table 1. In corn, hybrids with additional resistance to the leaf blights and tolerance to periods of drought would be desirable, even though present hybrids are reasonably good in these respects. Additional factors in corn,, which are important because they affect the proportion of the crop which can be harvested, are stalk rots and weevil infestation. With permanent pasture grasses, the main factors are low nutritive value of mature plants, short growing season, and susceptibility to drought and cold. In oats, susceptibility to new races of crown rust has been and probably will continue to be the most important factor. Other diseases in oats are also important, and lodging limits production indirectly because it occurs when high fertilizer rates are used. Peanut yields of present

varieties are limited to some extent by small size of the nuts, since large size and high yields are closely correlated. However, large nuts are more difficult to cure without damage. Another important factor with peanuts is the tendency for loss of nuts in the soil, especially if digging is delayed by bad weather. In rye, low seed production and susceptibility to some diseases appear to be the most important factors. Soybean production in central and south Florida is limited by lack of good varieties adapted to the day lengths of those areas; susceptibility to diseases, nematodes, and shattering are important in north Florida. In sugarcane, resistance to diseases, insects, and cold, and high quality (high sugar and low fiber content) are the main factors required in new varieties. In tobacco, diseases and nematodes, along with quality, appear to be the most important factors. Breeding for nematode root-knot resistance at Gainesville has been successful. In white clover, summer persistence seems to be limited by susceptibility to drought and diseases.

TABLE 1.—IMPORTANT LIMITING FACTORS IN AVAILABLE VARIETIES OF THE "ADAPTED" GROUP OF CROPS.

Crop	Limiting Factor (s)
Corn	Susceptibility to stalk rots, leaf blights, rice weevil, and drought.
Grasses	Low nutritive value; drought and cold susceptibility; short growing season.
Oats	Disease and lodging susceptibility.
Peanuts	Small seed; poor nut holding capacity; susceptibility to diseases and drought.
Rye	Disease susceptibility.
Soybeans	Adaptation to day length; diseases and nematodes; shattering; quality.
Sugarcane	Low sugar content; susceptibility to diseases, insects, and cold; high fiber; short life.
Tobacco	Susceptibility to nematodes and diseases; low quality.
White Clover	Susceptibility to diseases and drought.

Unadapted Crops

The more important factors which limit production in the "unadapted" group of crops are listed in Table 2. Alfalfa, which is potentially a valuable hay crop in Florida, is limited by lack of summer persistence. Probably disease and inability to compete with summer weeds are primarily responsible. Recent results at Gainesville indicate that it will be possible to develop improved varieties of alfalfa for Florida. Barley cannot be grown in Florida at present because of two diseases, spot blotch and net blotch. Crotalaria (*C. spectabilis* and *C. mucronata*) is well adapted to Florida but cannot be grown because of toxicity to animals. Lupines, which were much more widely grown in north Florida in the late 1940's than now, are limited primarily by diseases; also important are susceptibility to cold and to shattering. Red clover lacks disease resistance and persistency. Sorghum is of potential value because it is more drought tolerant and more resistant to foliage-eating insects than corn and therefore can be

planted later than corn. However, present grain varieties are susceptible to damage by head molds and birds and give low yields in late plantings. Forage varieties utilized as silage are low in quality. Wheat is grown on about 60,000 acres in west Florida, but production is limited by mildew and rust.

TABLE 2.—IMPORTANT LIMITING FACTORS IN AVAILABLE VARIETIES OF THE "UNADAPTED" GROUP OF CROPS.

Crop	Limiting Factor (s)
Alfalfa	Diseases; lack of summer persistence.
Barley	Diseases.
Crotalaria	Toxicity to animals.
Lupines	Diseases; insects; shattering; lack of cold tolerance.
Red Clover	Diseases; lack of summer persistence.
Sorghum	Head mold; birds; low yield in late plantings.
Wheat	Diseases.

SUMMARY

The productivity of any crop variety is the result of complex interactions between heredity and the environment. Field crop production in Florida is on a more stable basis now than it was before improved varieties were bred or introduced. However, yields often fall short of the high level we desire because of certain factors which limit the potential at one stage or another. The single factor which affects nearly all crops in Florida is disease. The only economical way of controlling diseases in field crops is by breeding resistant varieties. Adequate resistance for economical production is present in improved varieties of corn, pasture grasses, oats, peanuts, rye, soybeans, sugarcane, and tobacco. Nevertheless there is still room for improvement in all of these crops. Crops in which we do not have adequate resistance at present are lupines, barley, wheat, alfalfa, and red clover. Other important factors which either limit production or limit the value of the harvested crop are susceptibility to drought, lodging, and insect attack; poor quality or chemical composition; and lack of adaptation to local environmental conditions. It appears possible to further improve present varieties of all field crops in Florida in the factors discussed in this paper. In addition to breeding to overcome specific limiting factors, it will be necessary to develop varieties which can better utilize optimum soil conditions if maximum production is to be obtained.

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LITERATURE CITED

1. Bregger, T., P. H. Dunckelman, F. leGrand, E. H. Todd, and D. D. Questel. A brief review of sugarcane research in Florida, 1939-1959. Soil and Crop Sci. Soc. Fla. Proc. 19: 287-294. 1959.
2. Carver, W. A. Peanut breeding in Florida. Soil and Crop Sci. Soc. Fla. Proc. 19: 115-118. 1959.
3. Chapman, W. H. Small grain breeding in Florida during the past twenty years. Soil and Crop Sci. Soc. Fla. Proc. 19: 91-98. 1959.
4. Hinson, Kuell. Soybean breeding in Florida. Soil and Crop Sci. Soc. Fla. Proc. 19: 105-114. 1959.
5. Tisdale, W. B. Development of strains of cigar-wrapper tobacco resistant to black shank (*Phytopythora nicotinae* Breda de Haan). Florida Agr. Exp. Sta. Bul. 226. 1931.

Limiting Factors in Field Crop Production in Northwestern Florida[1]

C. E. HUTTON, M. C. LUTRICK and W. K. ROBERTSON[2]

Yields of all of the agricultural crops grown in northwest Florida have been increased in recent years. This increase has been due to several factors which have acted in a complimentary manner. Among the more important contributing factors are: (1) an increase in fertilizer usage, (2) the development of better adapted crop varieties, (3) improved agricultural equipment, (4) more efficient insect and disease control and (5) more available scientific information on crop and soil requirements.

The knowledge required to combine these factors in an optimum manner is fairly well understood, but weather conditions may have such an effect as to limit maximum yields. However, some of these conditions can be modified. For instance, irrigation may be used to alleviate drouth conditions, and drainage control may remove excess water. Other naturally occurring phenomena such as day length, light intensity, heat or cold intensity and sudden extremes in some of these conditions cannot be easily controlled. These uncontrollable factors will play an important role in future agricultural research because even though recent advances in crop production have been rapid there have been keen disappointments in many areas where apparent yield ceilings have been reached. Thus, the large crop yield increases, which were being obtained as late as ten years ago by simply applying more fertilizer, are no longer being experienced by the researcher. There still are refinements in fertilizer usage to be made for some crops on quite a few soil areas, but the "hit and miss" practical type research in northwest Florida must be abandoned in favor of a much needed basic agronomic research program.

This paper is presented to show the progress which has been made in crop yields within recent years, the effect of fertilizer usage on the nutrient status of the soil, and to place emphasis on some of the factors which are limiting further yield increases.

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METHODS AND MATERIALS

The following experimental data will show the agronomic sequences which have been used to combine varietal adaptation, plant food requirements, moisture requirements, and other related factors to arrive at the present limit of crop yields in this soil area. It will not be possible to fully treat all of the crops on all of the various types of soil. The discussion will be confined to the more important row crops on the better agricultural soils.

Unless otherwise stated, the data pertain to experiments at the West Florida Station. Corn is the indicator crop in much of the work reported because it is an important crop and because it shows a straightforward response to fertilizer nutrients. Except for some observational work, which is amply noted in the text, these data are averages of statistically sound experiments. Some of these data are presented elsewhere in greater detail (3, 4, 5, 6).

RESULTS

Presented in Table 1 are average crop yields for the entire State of Florida from 1920-59 for corn and peanuts and from 1950-59 for soybeans. These figures show that corn and peanut yields have gradually increased during this period but with the most rapid increase coming since 1950. Soybeans were not an important crop in Florida prior to 1950. It is likely that the average soybean yield is being depressed somewhat because of a rapidly expanding acreage of this crop. While we recognize that state averages of crop yields are not too meaningful, they do serve to show trends and are presented here for that purpose.

TABLE 1.—AVERAGE CROP YIELD IN FLORIDA

Crop	Year												
	1920	1925	1930	1935	1940	1945	1950	1954	1955	1956	1957	1958	1959
Corn	11	12	11	9	8	11	12	17	19	21	24	26	27
Peanuts	180	----	----	----	460	620	650	810	1025	1075	925	1120	960
Soybeans	----	----	----	----	----	----	20	12	22	22	23	25	23

All figures represent bushels per acre with the exception of peanuts which is in pounds per acre.

Data in Table 2 show the yield of corn obtained between 1950-57 on an unirrigated five-level NPK factorial experiment. Each value represents an average of ten measurements where two nutrients are at the highest fertility level and the third is an average of all treatment levels. Data from the entire experiment show the following: from a fertility standpoint, P_2O_5 is the first limiting factor in corn production followed closely by nitrogen. Potassium gives a consistent but less striking response. The data in this table also show that moisture was a seriously limiting factor in 1952, 1954, and 1955 and to a lesser degree in 1953 and 1957. Statistical treatment of data from this experiment indicates that the yields reported

TABLE 2.—CORN YIELDS FROM A 5 x 5 x 5 FACTORIAL EXPERIMENT.

Annual Treatment Levels										
N	P_2O_5	K_2O								
Ave.*	240	120	64**	66	23	65	55	49	66	47
120	Ave.	120	62	68	19	56	43	42	67	54
120	240	Ave.	72	86	21	62	43	46	83	68

*—Refers to the average value of yields (limed and unlimed) at all levels of the nutrient when in the specified combination of the other two. For N and K_2O the levels were 0, 15, 30, 60, 120 and for P_2O_5, levels were 0, 30, 60, 120, 240 pounds per acre.

**—Yield in bushels per acre, Dixie 18 variety.

approach a maximum expected yield for the moisture conditions of that particular year.

In 1955, an experiment was modified to study the effect of residual phosphorus and residual potassium on corn yields. The P_2O_5 residual data for 1955-60 are shown in Table 3. These data show an excellent response to residual phosphorus in the soil when 0, 30 or 60 pounds of P_2O_5 per acre are added uniformly to all plots. As would be expected, P_1 and P_2 treatments, which have not received phosphate fertilizer since 1955, show a decline in yield with years. As a matter of interest, the high yield of 30 bushels of corn per acre in 1955 on the P_1 treatment is due primarily to the residual effect of an application of 30 pounds per acre rate of radioactive phosphorus added to one row of each plot in 1954.

These data show the effectiveness of 30 and 60-pound applications of P_2O_5 to areas which have had little or no phosphorus applied previously.

TABLE 3.—CORN YIELD RESPONSE TO RESIDUAL PHOSPHORUS.

Residual Level	1955			1956			1957			1958			1959			1960		
	0*	30*	60*	0	30	60	0	30	60	0	30	60	0	30	60	0	30	60
P_1	30**	34	....	25	55	51	20	52	58	19	62	70	12	64	72	12	50	54
P_2	40	41	....	47	62	61	44	62	61	40	68	75	32	69	70	23	52	52
P_3	50	41	....	63	73	62	62	62	68	60	76	78	55	76	65	41	51	57
P_4	56	43	....	71	81	78	76	68	69	74	80	81	75	84	84	61	59	56
P_5	73	47	....	72	83	77	81	73	75	76	84	83	82	83	85	82	61	61

*Figures refer to annual P_2O_5 application. All treatments received annual application of 120 pounds of N and 120 pounds of K_2O per acre.

**Average of 5 replications in bushels per acre, Dixie 18 variety.

Annual Phosphorus Fertilization (1950-54)

P_1— 0 Lbs. P_2O_5/Acre
P_2— 30 " " "
P_3— 60 " " "
P_4—120 " " "
P_5—240 " " "

They also show that there is a fair response to these annual applications even on areas which have had high rates of P_2O_5 during a previous five-year period.

Data in Table 3 indicate the possibility that moisture limited yields in 1955, 1957 and 1960. They also show an important soil difference insofar as moisture conditions are concerned. The experiment which received 120-0-120 each year was on a soil area which has a better water holding capacity and poorer internal drainage than the soil area on which the other two experiments were located. The difference in the abilities of the two soils to supply moisture to the corn plants shows up in yield differences only in years like 1955, 1957 and 1960 when there was a serious moisture shortage.

A similar study was conducted concurrently to measure corn yield response to residual potassium. These data, presented in Table 4, show only a slight response to residual potassium and to the 30 pound increment of K_2O applied uniformly to all residual treatments. It is important to note, however, that the average yield of the 0-treatment is more than 60 bushels of corn per acre. These data confirm moisture to be the limiting factor in corn production in 1955 and 1960 and possibly in 1956 and 1957.

During the time these experiments were being conducted, it became evident that moisture conditions must be controlled for a maximum corn yield. In 1954, an experiment was designed to determine the effect of supplemental water at two levels of N and at two plant populations. These data are outlined in Table 5. They show a large response to added water and a favorable increase for the higher stalk population under irrigated conditions. At this point, we would like to call attention to the 100 bushel maximum yield. This approximate limit will recur again and again in data to be presented.

TABLE 4.—CORN YIELD RESPONSE TO RESIDUAL POTASSIUM

Residual Level	1955		1956		1957		1958		1959		1960		Average	
	0*	30*	0	30	0	30	0	30	0	30	0	30	0	30
K_1	42**	40	76	68	65	68	73	87	70	80	51	59	62.8	67.0
K_2	49	48	77	78	67	75	73	81	68	81	53	65	64.5	71.3
K_3	48	47	78	72	71	71	78	83	78	84	63	62	69.3	70.3
K_4	50	49	76	82	73	75	78	83	82	89	59	62	69.7	73.3
K_5	51	45	74	72	73	68	79	85	83	80	58	61	69.7	68.5

*Figures refer to annual K_2O application. All treatments received annual application of 120 pounds of N and 240 pounds of P_2O_5 per acre.

**Average of 5 replications in bushels per acre, Dixie 18 variety.

Annual Potassium Fertilization (1950-54)

K_1— 0 Lbs. K_2O/Acre
K_2— 15 " "
K_3— 30 " "
K_4— 60 " "
K_5—120 " "

TABLE 5.—EFFECT OF STALK POPULATION, NITROGEN LEVEL AND IRRIGATION ON CORN YIELD.

Stalk Population	Fertility Level 120-240-240 Irrigated	120-240-240 Unirrigated	200-240-240 Irrigated	200-240-240 Unirrigated
10,000	92*	54	90	54
20,000	100	57	101	56

*Average of 5 replications in bushels per acre, Dixie 18 variety.

In 1955, the irrigation work was expanded to further study the effect of N, P_2O_5 and supplemental water on corn production. These data are shown in Table 6. In this experiment, the fertility is at a level that is considered to be higher than the corn plants can possibly use. Except for the basic applications, these fertility levels were applied annually. Here again, maximum yields were only slightly over 100 bushels in 1955. The lower yields in 1957 are probably due to a severe outbreak of Northern corn blight, (Helminthosporium turcicum).

In 1957, an effort was made to determine the maximum yield possible. Ten tons per acre of rotted silage material on a dry weight basis and a fertilizer rate of 175-120-120 was applied on a soil area of high residual fertility. Two replications received supplemental light, consisting of 400 foot-candles at three feet and 2,000 foot-candles at one foot from the source, for a five-hour period nightly from tasseling time to maturity as a treatment variable. The Florida 200 variety of corn made an average yield of 98 bushels per acre with additional light and 90 bushels per acre without additional light.

In 1958, corn and soybeans were grown under irrigation using extreme-

TABLE 6.—EFFECT OF HIGH RATES OF N AND P_2O_5 ON CORN YIELD.

Fertility Level	1955 Irrigated	1955 Unirrigated	1956 Unirrigated**	1957 Unirrigated**
120-280-200	93*	78	95	58
180-280-200	98	80	92	55
240-280-200	109	82	94	52
300-280-200	110	83	92	59
360-280-200	105	83	90	56
360- 40-200	90	63	82	49
360-100-200	92	70	84	52
360-160-200	104	78	91	62
360-220-200	103	78	93	57

*Average of 4 replications, Dixie 18, variety, Stalk Population—10,000.

**No significant difference between irrigated and unirrigated treatments. Figures are average of 8 replications. In 1957 Northern corn blight was severe and probably reduced yields.

Basic Treatment:

216 pounds of P_2O_5 and 2500 pounds of dolomitic limestone broadcast and disked into soil on April 1, 1955. Two tons dolomite applied March, 1956.

TABLE 7.—EFFECT OF HIGH FERTILITY ON CORN YIELD.

P_2O_5 Fertility	K_2O Fertility		
	0	180	360
0	96*	100	84
60	82	84	80
120	83	80	97
180	77	76	76
240	69	71	95
300	75	75	103

200 pounds of N added to all treatments.
*Yields in bushels per acre.

TABLE 8.—EFFECT OF HIGH FERTILITY LEVEL ON SOYBEAN YIELD.

P_2O_5 Fertility	K_2O Fertility		
	0	180	360
0	44*	47	37
60	47	46	43
120	49	49	44
180	49	44	42
240	48	46	41
300	36	31	43

*Yields in bushels per acre.

ly high fertility to further determine maximum yield possibilities. These values are presented on an observational basis only, but do serve to substantiate other data presented here. These values were obtained on an experimental area which had been highly fertilized with mineral fertilizers for several years. In addition, approximately 100 tons per acre of dry organic matter was uniformly applied to the area prior to the planting season. Inorganic fertility added and yield in bushels per acre for 1958 are shown in Tables 7 and 8 for corn and soybeans, respectively.

These data show that the residual fertility plus those nutrients derived from the added organic matter was sufficient to produce yields which approached the highest yield observed for any treatment. They also show a definite trend toward lower yields with increasing rates of both P_2O_5 and K_2O. The exception in this trend is at the highest level of P_2O_5 and K_2O for both corn and soybean yields. However, the downward trend seems to be definite for soybeans and there is no apparent upward trend for corn yields.

In 1956, several leading corn varieties were grown under high fertility plus irrigation and under normal fertility. The fertility levels were 200-96-96 on a soil already high in residual P_2O_5 and K_2O and 90-72-72 on a soil with an average residual level. Yield data in bushels per acre are shown in Table 9. These data indicate, as has been found in other data, the ease of producing up to 75 bushels of corn under average fertilizer practices and fair to good moisture conditions. They also indicate that approximate-

TABLE 9.—EFFECT OF VARIETY ON CORN YIELD.

Variety	High Fertility Plus Irrigation	Normal Fertility Minus Irrigation
Dixie 18	103*	77
Fla. 200	95	78
Coker 67	94	73
Coker 811	93	74
Coker 71	87	75

*Yields in bushels per acre.

ly 100 bushels of corn can be produced under conditions of high fertility when moisture is sufficient either from natural or irrigation sources.

It is important to know the effect of fertilization on the nutrient status of these soils. The virgin Red Bay fine sandy loam, on which much of this work was done, contained bases extractable with acid ammonium acetate as follows: Ca—300, Mg—50, and K_2O—120 pounds per acre. P_2O_5 extracted by the strong Bray method (2) averaged 50 pounds per acre.

When three tons of dolomitic limestone were added to these soils by 1951, extractable calcium and magnesium increased to 900 and 400 pounds per acre, respectively by 1955-56 and to 550 and 170 pounds per acre, respectively by 1960. However, on plots where high rates of superphosphate were applied annually, extractable Ca increased to more than 1,000 pounds per acre by 1960.

In areas where 240 pounds of P_2O_5 per acre was applied annually, the extractable P_2O_5 increased yearly to values of 600 pounds per acre by 1956. However, where no additional phosphorus was added to this treatment after the 1954 crop season, the extractable P_2O_5 decreased to approximately 300 pounds per acre by 1960. This indicates a change in the chemical makeup of soil phosphorus, or a change in the physical condition within the soil rather than a loss by leaching or removal by crops (1, 6).

In areas where 120 pounds of K_2O was applied annually, the amount of extractable K_2O in the surface six inches varied with annual rainfall. After extremely dry years, the values of K_2O were 250 pounds per acre. As an average of all years, the original K_2O level has been maintained where 60 pounds and slightly increased where 120 pounds of K_2O have been applied annually. However, it has been shown by Robertson and Hutton (6) on treatments receiving 30, 60, or 120 pounds of K_2O annually from 1950-54 that all but 20-35 percent of it can still be accounted for in the top 36 inches of soil in 1958.

DISCUSSION AND SUMMARY

An attempt has been made to show through a sequence of experimental work, using corn as the indicator crop, the factors limiting field crop production on northwestern Florida soils. There are a number of factors which limit crop production, of which some can be controlled while others can not.

From the nutritional standpoint on virgin soils, phosphorus is the first limiting factor until enough has been added to the soil, either at one time or over a period of years, to provide a residual level high enough for good plant growth. Nitrogen is the next limiting factor in the growth of non-legumes. Potassium is present in a good supply on most virgin soils but is readily depleted by continued crop production and a poor fertility program. It becomes apparent that to state the limiting major nutritional element, one must know the fertilizer and cropping history of the soil area involved. Since this is not always possible, a soil analysis is the most satisfactory method of determining the requirements for good plant growth.

Calcium, when applied at rates of approximately two tons per acre, has improved crop yields (4). Higher applications up to about six tons per acre have had no additional effect while applications above the six ton rate have introduced a zinc deficiency on some crops. This deficiency is

easily corrected with one application of 20 pounds of zinc sulphate per acre. No benefit has been found from the application of any other minor element on any of the field crops grown (3).

Through the application of this basic information, it is possible to eliminate mineral nutrition as a limiting factor in crop production. We have shown, in the experiments cited, that no additional corn yield may be obtained by increasing rates of the mineral nutrients. This maximum yield may be near 100 bushels of corn in years when moisture supply is ample and well distributed or it may be 20 bushels per acre, as it was in 1952, when moisture conditions were poor. In average years, yields more likely will be from 60-85 bushels per acre. Under the latter two conditions then, moisture becomes the factor which limits crop yield.

If more than an ample amount of nutrients are supplied plus sufficient moisture, the yield of corn obtained still is only slightly above 100 bushels per acre. In addition, the extension of day length, high rates of easily decomposable organic matter for CO_2 production, and increasing the plant population to as many as 43,560 stalks per acre have failed to further increase the yield of the best adapted corn varieties.

From these data it may be concluded that the genetic makeup of the available corn varieties is the main limiting factor in increasing corn yields above 100 bushels per acre. Although data have not been presented, this same condition of varietal limitation on yield is generally true for other crops grown in this area under optimum moisture conditions.

There are now available well adapted varieties of all the field crops capable of producing higher yields than average natural weather conditions will allow. At the same time, there appears to be an upper limit of production even though the nutrient requirements have been satisfied and all natural conditions have been controlled insofar as possible. The average difference between the best yields with and without irrigation is not sufficient to make irrigation an economic operation under existing conditions. Herein lies an important fact. The next great advance in field crop production must be made by the plant breeder through the introduction of new or a recombination of the old genetic makeup of the field crop varieties.

LITERATURE CITED

1. Beeson, K. C. The mineral composition of crops with particular reference to the soils in which they were grown. U.S.D.A. Misc. Pub. 369. 1941.
2. Bray, R. H. and L. T. Kurtz. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59:39-45. 1945.
3. Hutton, C. E. and W. K. Robertson. A study of minor element applications on West Florida Soils. Soil Sci. Soc. Fla. Proc. 14:100-110. 1954.
4. ——————, and W. D. Hanson. Four years of soil fertility data from a 5x5x5x2 factorial experiment on Red Bay fine sandy loam. I Corn. Soil Sci. Soc. Am. Proc. 20:531-537. 1956.
5. Robertson, W. K. and C. E. Hutton. An evaluation of ten phosphorus sources by growth of four field crops. Agron. Jour. 50:24-28. 1958.
6. —————— and ——————. Retention of fertilizer elements in Red Bay fine sandy loam. Soil and Crop Sci. Soc. Fla. Proc. 20: 158-166. 1960.

Factors Limiting Field Crop Production in North Central Florida[1]

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The soils in central Florida consist primarily of fine sands. They are all low in native fertility but vary in their drainage characteristics. The soils with the poorest drainage characteristics are known as flatwoods. They usually have an organic hardpan 14 to 18 inches beneath the surface and during periods of heavy rainfall have a water table at or near the soil surface. The remainder of these soils are either well drained or intermediately well drained.

During the last ten years many fertility experiments have been conducted in central Florida. Blue and Eno (1) found in studies on peanuts that magnesium was a limiting element in a large number of Suwannee County soils. Wofford *et al.* (9) concluded that 79, 220 and 160 lb. per acre of nitrogen applied to corn with stand counts of 7000, 11000 and 13000 stalks per acre respectively gave the best yields on Arredonda fine sand. Lime studies summarized by Robertson *et al.* (8) indicated that lime was a first requirement for most farm crops on many Florida soils. Peanut studies conducted by Harris and Bledsoe in Florida and York and Colwell in North Carolina are summarized in a book entitled "The Peanut—The Unpredictable Legume" (4). They showed the need for calcium in the fruiting zone and certain minor elements for peanut production. This paper is intended to determine to what extent fertilizers, lime and minor elements limit field crop production on moderately well drained, somewhat poorly drained and poorly drained soils.

EXPERIMENTAL PROCEDURE

Moderately well drained soils:

Fertility, minor elements, nitrogen and lime experiments were conducted for six years on moderately well drained Klej fine sand near Live Oak. Klej fine sand has been described (2) as a group of soils which have nearly-level to rolling relief and derived from moderately-thick beds of sand. Treatments in all experiments conducted on two and three year rotations had two and three blocks respectively each containing all treatments so that all crops appeared each year.

The fertility experiment consisted of a 4 x 4 x 4 factorial of N, P and K with lime introduced using the split plot technique on a three-year rotation consisting of lupines plowed down for corn the first year, oats for grain followed by soybeans the second year and oats for green manure followed by peanuts the third year. Details of the fertilizer treatments are presented in Table 1. Ammonium nitrate, superphosphate and muriate of potash were the sources of nitrogen, phosphorus and potassium respectively. High calcic lime was applied at the rate of 3,000 pounds per acre.

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TABLE 1.—CORN RESPONSE TO NITROGEN, PHOSPHORUS AND POTASH ON LIMED[1] KLEJ FINE SAND.

Treatment	Yield						
N-P_2O_5-K_2O	1954	1955	1956	1957	1958	1959	Ave.
lbs./A.				bushels per acre			
0-0-0	22	17	8	13	26	13	16
0-60-60	28	18	23	17	35	36	26
40-60-60	41	24	28	32	49	56	38
80-60-60	36	32	34	37	52	54	41
120-60-60	38	26	34	33	50	44	38
120-0-60	39	27	31	40	59	44	40
120-20-60	43	28	37	39	53	48	41
120-40-60	38	29	31	33	48	52	39
120-60-60	38	26	34	33	50	44	38
120-60-0	34	18	18	17	32	22	24
120-60-20	38	26	26	20	50	43	34
120-60-40	36	29	30	22	55	42	36
120-60-60	38	26	34	33	50	44	38
L.S.D. 5%	6	10	6	7	9	13	10
L.S.D. 1%	8	N.S.	8	9	11	18	13

[1]An application of 3000 lbs. per acre of coarse, high calcic lime was applied at the beginning of the experiment.

The minor element experiment tested the effect of annual applications of 2, 2, 2, 0.2 and 1 pound per acre of Zn, Cu, Mn, Mo and B on the crops in a two-year rotation of lupines plowed down for corn the first year followed by oats plowed for peanuts the second year. Zn, Co and Mn were applied in the sulfate form, Mo as ammonium molybdate and B as the oxide, Colmanite. As in the fertility experiment, lime was applied to half of each plot.

The nitrogen experiment compared 3 sources of nitrogen applied at 5 rates to corn. The treatments are listed in Table 2.

The lime experiment compared 0, 1000, 2000, 4000 and 8000 pounds per acre of dolomite and high calcic lime on two-year rotations similar to the minor element experiment.

Yield data as well as soil and plant analyses were used to measure responses. Soil samples were taken to a depth of 6 inches every year before fertilization from the lime and minor element experiments and on alternate years from the fertility experiment. Ear leaf samples were taken from the corn plots. Profile samples were taken to a depth of 24 inches from the fertility plots on the fifth year of the fertility experiment. The pH, exchangeable calcium, magnesium and potassium, and acetic acid soluble phosphorus were determined on the soil samples. Calcium, magnesium, potassium and phosphorus were determined on the plant samples. Calcium and potassium were determined on the Beckman DU flame photometer using the hydrogen flame. Magnesium was determined colorimetrically (5).

Somewhat poorly drained soils:

Exploratory type experiments were carried out near Gainesville on a Kanapaha-Ona fine sand complex. Kanapaha fine sands (3) are derived

TABLE 2.—EFFECT OF RATES AND SOURCES OF NITROGEN ON CORN YIELD ON KLEJ FINE SAND.

Nitrogen Rate	Anhydrous Ammonia				NH_4NO_3[1]		$NaNO_3$[1]	
	Planting		Knee High					
	1957	1958	1957	1958	1957	1958	1957	1958
Lbs./A.	Bushels/A.							
0	14	16	14	16	14	16	14	16
20	16	35	34	24	26	25	23	26
40	26	41	36	24	32	30	27	25
80	31	56	38	28	40	36	26	21
120	27	49	39	32	42	36	23	24

	Rates		Sources	
	1957	1958	1957	1958
L.S.D. 5%	13	6	11	6
1%	18	9	15	9

[1]Split application, half at planting half when knee high.

from a mixture of sands and phosphatic materials. These soils occur on nearly level to rolling relief and are dominantly well to moderately well drained, and have a grayish-brown to dark gray surface over pale brown, light gray or pale yellow lower layers. The Ona soil has been described as a poorly drained soil with a hardpan near the surface. The Kanapaha-Ona complex was considered to be somewhat poorly drained.

The experiments were designed to evaluate rates of a complete fertilizer (4-12-12) and to compare nitrogen applied in 2, 3 and 4 increments. Corn yields and chemical data from prefertilization soil profile samples similar to those in the fertility experiment were used to measure responses.

Poorly drained soils:

Raising the subsoil fertility and breaking the hardpan was compared with surface fertilization and cultivation on a poorly drained Leon fine sand. Yield, root observations and soil and plant chemical data similar to those used in experiments on Klej fine sand were the criteria of response. These soils have been described and yield data has been reported (6); however, part of the results will be used in this paper to illustrate the limiting factors on flatwoods soils.

RESULTS AND DISCUSSION

Moderately well drained soils:

Table 1 contains the corn yield data from the fertility experiment. Data are from the limed plots. The nitrogen response leveled off between 40 and 80 pounds per acre of nitrogen. Lupines contributed some nitrogen to the corn but some years lupine yields were negligible due to insects and disease. There was no consistent response to phosphorus. Ammonium fluoride extractable phosphorus was high in the untreated soil (Table 9). There was a significant response on the average for 20 pounds of K_2O per acre, but additional potassium increased yields only 4 bushels. Considering the low nitrogen and potassium (Table 9) in the soil it seemed that there

should have been a better response to these elements. The reasons for this might be: first, the soil being sandy was not able to hold enough nitrogen and potassium and the corn suffered from a deficiency of one or both; secondly, minor elements might be limiting yields; and thirdly, magnesium might be a factor since high calcic lime was used.

The first possibility might be refuted by a nitrogen experiment which tested higher rates than the fertility experiment and sources of nitrogen at high levels of phosphorus and potassium. Yield data are shown in Table 2. Yield responses were obtained up to 80 pounds per acre. The best average yield was obtained from anhydrous ammonia followed by ammonium nitrate and sodium nitrate. But regardless of rate or source of nitrogen the yield limit was even less than that shown in Table 1.

The data in Table 3 showing plant yield and soil correlations indicate that potassium was probably not the limiting element for 1958. Exchangeable potassium accumulated in the soil and the increasing levels are correlated with higher plant content. Yields level off at the 20 pounds per acre rate of application.

The experiment on minor elements would probably eliminate the second possibility. Adding B, Mo, Mn, Zn or Cu did not improve corn or peanut yields significantly.

An attempt was made to test the effect of adding magnesium in 1960. The unlimed plots of the fertility experiment were treated with rates of dolomite up to 6000 pounds per acre, and there was a treatment with magnesium sulfate and magnesium sulfate plus high calcic lime. Lime applications were made just prior to corn planting. A list of the treatments with yields, plant and soils data are shown in Table 4. Soil samples were taken following harvest.

Dolomite improved corn yields up to the 1000 pounds per acre rate but the best yield was obtained for 200 pounds of MgO from magnesium sulfate and 1000 pounds per acre of high calcic lime. The latter treatment raised the calcium slightly and the magnesium significantly in the plant above the values for the 1000 pounds per acre of dolomite. However, the soils data indicate that Mg from magnesium sulfate was not retained. Despite the high rates of dolomite corn yields did not exceed 54 bushels per acre.

Although the three limitations suggested for the low yield limit are not

TABLE 3.—DATA SHOWING POTASSIUM REQUIREMENTS OF CORN GROWN ON KLEJ FINE SAND.

Treatment		1958	Potassium Data	
No.	$N - P_2O_5 - K_2O$	Corn Yield	In Ear Leaf	In Soil[1]
	lbs./A	lbs./A	%	lbs./A
1	120-60-0	32	0.5	58
2	120-60-20	50	1.2	74
3	120-60-40	55	1.2	105
4	120-60-60	50	2.0	134
	L.S.D. 5%	9	0.3	
	L.S.D. 1%	11	0.4	

[1]There was approximately 53 inches of well-distributed rainfall between fertilization and soil sampling.

TABLE 4.—EFFECT OF LIME ON CORN YIELDS AND PLANT AND SOIL ANALYSES.

Treatment (lbs/A)				Plant Data[2]				Soils Data				
	Dolomite	MgO[1]	Corn	P	K	Ca	Mg	pH	P_2O_5	K_2O	Ca	Mg
	lbs./A.		bu./A.	%				lbs./A.[3]				
1.	0	0	25	.22	1.4	.16	.21	5.3	23	48	29	19
2.	250	0	18	.21	1.2	.15	.24	5.3	25	40	32	29
3.	500	0	21	.24	1.3	.16	.35	5.2	29	38	32	23
4.	1000	0	38	.21	1.3	.23	.34	5.7	31	63	93	56
5.	1500	0	30	.25	1.2	.23	.42	5.7	36	53	128	51
6.	2500	0	36	.21	1.2	.23	.46	6.1	41	72	552	187
7.	3000	0	42	.26	1.2	.23	.47	5.9	31	58	348	131
8.	5000	0	38	.26	1.2	.22	.48	6.3	33	68	517	209
9.	6000	0	45	.25	1.3	.22	.46	6.4	44	82	565	236
10.	0	200	44	.23	1.3	.20	.44	5.5	45	60	48	23
11.[4]	0	200	54	.20	1.2	.24	.46	5.6	36	60	173	22
		L.S.D. 5%	15	N.S.	N.S.	.05	.06	0.4	N.S.	N.S.	206	67
		L.S.D. 1%	20			.06	.08	0.5			274	90

[1]Source of Magnesium was Mg SO_4

[2]In ear and leaf.

[3]Acid acetate soluble.

[4]Also received 1000 lbs/A. high calcic lime.

completely satisfied, the data suggest that nitrogen, phosphorus, potash, minor elements, calcium and magnesium are not the major factors limiting the yield potential. Moisture was not controlled and it is suspected that lack of adequate moisture was a limiting factor in most years.

The peanut data from the fertility experiment on Klej fine sand showed an approaching significance at the 5% level for potassium yield response at the 20 pound rate, but yields for additional potassium decreased. The decrease may have been due to application in the row. It has been shown that potassium in excess of 30 pounds per acre applied in the row may decrease yields (7).

Table 6 contains data to show rye and soybean yield response for the major elements on Klej fine sand. Yield responses were obtained for nitro-

TABLE 5.—DATA TO SHOW POTASSIUM RESPONSE OF PEANUTS GROWN ON KLEJ FINE SAND.

Treatment		1958	Potassium Data	
No.	N - P_2O_5 - K_2O	Peanut Yield	In Top	In Soil[1]
	lbs./A	lbs./A	%	lbs./A
1	15-60-0	800	.8	25
2	15-60-20	1340	1.2	15
3	15-60-40	940	1.6	25
4	15-60-60	1060	1.9	40
	L.S.D. 5%	NS	0.6	
	L.S.D. 1%		0.8	

[1]There were approximately 53 inches of well-distributed rainfall between fertilization and soil sampling.

TABLE 6.—RYE GRAIN AND SOYBEAN RESPONSE TO NITROGEN, PHOSPHORUS AND POTASH ON KLEJ FINE SAND.

Treatment	Rye Grain Yield		Treatment	Yield Soybeans		
$N-P_2O_5-K_2O$	1956	1958	$N-P_2O_5-K_2O$	1956	1958	1959
Lbs/A	Bu/A		Lbs/A	Bu/A		
0-0-0	7	7	0-0-0	2	7	2
0-60-60	9	8	0-60-60	8	34	8
40-60-60	8	18	5-60-60	4	33	11
80-60-60	10	23	10-60-60	8	27	12
120-60-60	11	23	15-60-60	6	25	11
120-0-60	14	23	15-0-60	7	23	7
120-20-60	14	19	15-20-60	9	25	8
120-40-60	12	28	15-40-60	6	30	8
120-60-60	11	23	15-60-60	6	25	11
120-60-0	11	14	15-60-0	2	10	2
120-60-20	10	20	15-60-20	7	21	8
120-60-40	14	17	15-60-40	6	26	8
120-60-60	11	23	15-60-60	6	25	11
L.S.D. 5%	3	3		N.S.	10	4
L.S.D. 1%	4	4			13	6

TABLE 7.—YIELD RESPONSE TO LIME[1] IN FERTILITY EXPERIMENT ON KLEJ FINE SAND.

	Yields Limed	Unlimed	Significance[2]
	Corn (Bu/A)		
1954	36	35	N.S.
1955	26	24	N.S.
1956	27	21	**
1957	28	12	**
1958	46	39	**
1959	41	8	**
	Peanuts (Lbs/A)		
1954	1330	760	**
1955	1760	1390	**
1956	1840	1040	**
1958	1040	460	**
	Rye (Bu/A)		
1956	14	13	N.S.
1958	18	10	**
	Soybeans (Bu/A)		
1956	6	2	**
1957	5	2	**
1958	24	0	**
1959	10	0	**

[1]pH of limed and unlimed plots was 5.8 and 5.2 on the average over the 5 year period. This was the result of approximately 2 tons per acre of coarse high calcic lime.

[2]N.S. indicates lack of significance at 5% level and 2 asterisks indicates significance at 1% level of probability.

gen and potash up to the 60 pounds per acre rate on rye, and potash to the 40 pounds per acre rate on soybeans. The irregular yields for rye and soybeans indicate that something other than major elements, possibly moisture or the need for better adapted varieties, had affected yield limits.

The lime response on corn, peanuts, rye and soybeans is shown in Table 7. It took two years for calcium to be deficient for corn and one year for rye. Lime improved peanut and soybean yields from the start of the experiment. Peanut yields and rye yields in 1957 were not taken because of weather conditions. Oat yields were not taken in 1955 because of low yields. Rye was substituted for oats starting in the fall of 1955. Soybean yields were too low to harvest in 1954 and 1955.

The 1959 peanut yield data from the lime experiments are correlated with plant data near maturity and soils data immediately after harvest in Table 8. There is considerable difference in the percent magnesium and calcium in the plant between the checks of the dolomite and high calcic experimental areas. Apparently the dolomite area had a higher initial fertility. It is clear from these data that magnesium is limiting the over all yields in the high calcic lime experiment.

In the dolomite experiment no peanut yield response was obtained for rates above 1000 pounds per acre of dolomite. This corresponded to corn response in Table 7. The exchangeable calcium and magnesium in the soil was 92 and 32 pounds per acre, respectively. Liming did not affect the recovery of phosphorus. It reduced the potassium uptake significantly but the trend was not consistent with increasing rates.

TABLE 8.—EFFECT OF LIME ON PEANUT YIELDS AND PLANT AND SOIL ANALYSES ON KLEJ FINE SAND.

		Plant Analyses[1]				Soils data[2]				
Dolomite	Yield	P	K	Ca	Mg	pH	P_2O_5	K_2O	Ca	Mg
Lbs/A	Lbs/A	%	%	%	%		Lbs/A	Lbs/A	Lbs/A	Lbs/A
0	1190	.24	2.4	.68	.46	5.2	23	27	16	6
1000	1570	.23	2.1	.61	.53	5.6	35	34	92	32
2000	1600	.24	2.1	.54	.55	5.6	37	30	136	20
4000	1500	.27	1.3	.45	.67	6.3	31	32	342	44
8000	1490	.26	1.6	.45	.80	6.5	46	32	629	146
L.S.D. 5%	210	N.S.	0.5	.11	.13	0.4	N.S.	N.S.	220	55
L.S.D. 1%	280		N.S.	.14	.17	0.6			300	72
Hi-Calcic										
0	360	.21	2.8	.49	.22	5.0	50	22	0	9
1000	1110	.23	2.4	.69	.21	5.4	45	24	60	8
2000	1050	.23	2.3	.68	.23	5.7	56	29	108	5
4000	1100	.24	2.3	1.07	.20	6.0	67	32	368	8
8000	1240	.26	2.0	1.15	.20	6.6	56	30	1048	2
L.S.D. 5%	530	N.S.	N.S.	N.S.	N.S.	0.4	N.S.	N.S.	207	N.S.
L.S.D. 1%	N.S.					0.5			299	

[1]P, Ca and Mg determined chemically and K determined using DU flame spectrophotometer

[2]Acid Acetate Soluble P_2O_5, K_2O, Ca and Mg.

Despite the low magnesium level in the plant, high calcic lime increased the peanut yield up to the 1000 pounds per acre rate of application. The 1000 pound treatment showed a soil pH of 5.4 and exchangeable calcium of 60 pounds per acre. Increasing rates of calcic lime had no effect on potassium or magnesium in the plant but did increase the uptake of calcium.

Table 9 contains data to show the effect of fertilizer and lime on pH phosphorus, potassium, calcium, magnesium and organic matter in 0-6", 6-12" and 12-18" layer or the profile. Fertilizer had little effect on the pH in the surface 12 inches but tended to reduce it in the 12-18" depth. Fertilizer and lime increased the pH over the fertilizer without lime plots 1.0, 0.7 and 0.3 units in the 0-6", 6-12" and 12-18" depth of the profile, respectively. Fertilizer increased the phosphorus in the profile but lime had no consistent effect. Fertilization increased the available potash but the difference was not significant. Lime plus fertilizer increased the exchangeable calcium and potash significantly above the check. Fertilizer and lime reduced the level of organic matter determined by the Walkley-Black method.

TABLE 9.—EFFECT OF FERTILIZER AND LIME TREATMENTS ON KLEJ FINE SAND.

	Depth in profile			
Determination[1]	0-6"	6-12"	12-18"	Average
		Unfertilized and unlimed		
pH	5.1	5.2	5.2	5.2
P_2O_5[2]	730	690	600	670
K_2O	15	10	8	11
Ca	16	24	14	18
Mg	10	10	8	9
O.M.	1.35	1.31	0.90	1.19
		Fertilized and unlimed		
pH	5.2	5.1	4.9	5.1
P_2O_5[2]	820	780	660	750
K_2O	23	14	8	15
Ca	22	16	14	17
Mg	13	8	8	10
		Fertilized and limed[3]		
pH	6.2	5.8	5.2	5.7
P_2O_5[2]	790	740	650	730
K_2O	29	32	22	28
Ca	285	75	16	125
Mg	41	18	9	23
O.M.	1.29	1.03	0.61	.98

[1] P_2O_5, K_2O, Ca & Mg in Lbs/A and O.M. in percent.
[2] Phosphorus extracted with .03 N NH_4F in .1N HCl.
[3] 3000 Lbs/A of coarse high calcic lime applied 3 years prior to sampling.

Somewhat poorly drained soils:

The treatments for the corn experiment on Kanapaha-Ona complex are shown with the yield data in Table 10. Chemical data from pre-fertilization samples are shown in Table 11. Despite the low level of calcium in the profile, corn yields of up to 109 bushels per acre were obtained. This yield was obtained for 800 pounds per acre of 4-12-12 applied at planting time with 160 pounds per acre of nitrogen from ammonium nitrate applied when the corn was knee high. Splitting the nitrogen application in two and three applications had no significant effect on corn yields. The year of the experiment (1960) had good rainfall distribution and apparently there were no rains heavy enough to affect the availability of the nitrogen treatments. Fertilizer affected stand. All treatments were planted at the same rate, but the lowest rates had the fewest stalks at harvest. Ears per stalk and ear weight increased significantly with fertilizer rates.

Poorly drained soils:

Data from a fertilizer placement experiment carried out in 1955 on Leon fine sand are shown in Table 12. Breaking the plow sole improved yields significantly and placement of fertilizer and lime 14" deep increased, although not significantly, yield and plant nutrient content over those when equivalent fertilizer and lime was applied on the surface. Corn on the deep treatment had a deeper and better developed root system than on the shallow placement of fertilizer which meant a larger reservoir of moisture for the plants. These data illustrate that breaking the plow sole and raising the fertility of the subsoil, especially with lime, are necessary if good yields are to be obtained consistently on flatwoods soils. Later experiments indicated that surface applied fertilizer was as good as deep placement when the season had no periods of moisture stress or the opposite extreme, when the periods of moisture stress were long (6).

TABLE 10.—THE 1960 CORN YIELD DATA FROM KANAPAHA-ONA COMPLEX.

Treatment						
No.	4-12-12	N[1]	Yield	Stalks Per Acre	Ears Per Stalk	Weight Per Ear
	lbs/A	lbs/A	bu/A	(1,000)		lbs.
1	0	0	46	13.4	0.84	.30
2	200	40 (1)	81	13.9	0.99	.43
3	400	80 (1)	91	15.7	0.93	.45
4	600	120 (1)	105	17.4	1.00	.44
5	800	160 (1)	109	18.0	0.94	.46
6	600	120 (2)	107	17.7	0.94	.47
7	600	120 (3)	105	15.3	1.08	.46
		L.S.D. 5%	11	2.1	.12	.03
		L.S.D. 1%	15	3.0	.48	.04

[1]Numbers in parenthesis indicate number of applications.

	Knee-high	Last Cult.	Tasselling Time
(1)	40, 80, 120 or 160	0	0
(2)	60	60	0
(3)	40	40	40

TABLE 11.—CHEMICAL ANALYSES DATA FROM PREFERTILIZATION SOIL SAMPLES FROM KANAPHA-ONA COMPLEX.

Depth	pH	Acid Acetate Soluble			
		P_2O_5	K_2O	Ca	Mg
in.		lbs/A			
0- 6	5.4	35	95	Trace	24
6-12	5.4	38	50	Trace	24
12-18	5.4	40	30	Trace	20

Conclusions:

Fertility experiments using row crops such as corn, peanuts, soybeans, rye and oats have been conducted on moderately well drained Klej fine sand, somewhat poorly drained Kanapaha-Ona complex and poorly drained Leon-Ona complex, located in central Florida.

It has been shown on moderately well drained soils that nitrogen and potassium and lime may give highly significant yield increases most years. However, the top yields are rarely over 50 bushels of corn on the well drained soils. Fertilizer, lime or minor elements were probably not the answer to the yield limit. Moisture distribution was suspected to be the controlling factor. Corn yields on the somewhat poorly drained soils went over 100 bushels per acre in response to an application of 600 pounds per acre of 4-12-12 and 120 pounds of nitrogen from ammonium nitrate at the knee high stage of growth when rainfall distribution was good and the stand was approximately 15000 stalks per acre. This soil produced good yields more consistently than the others planted. The high water table in the Leon-Ona complex in wet seasons and the poor drought resistance of crops during dry periods could be alleviated by subsoiling and deep placement during some seasons. These practices produced a deeper root system which provided a larger reservoir of moisture and helped the crop through short dry periods. During wet seasons and seasons with

TABLE 12.—CORN YIELD AND CHEMICAL DATA FROM CORN EAR LEAF FROM LEON FINE SAND.

Treatment[1]			Depth	Corn Yield	Ear Leaf Content		
No.	High Calcic Lime	Fertilizer			P	Ca	K
	lbs/A	lbs/A	in.	bu/A	%	%	%
1	0	0	0	60	0.24	0.23	2.30
2	0	0	14	70	0.26	0.24	2.30
3	3100	0	14	72	0.23	0.27	2.43
4	0	110-110-110	14	81	0.33	0.24	2.61
5	2500	60-60-60	14	82	0.29	0.27	2.61
6	2500	60-60-60	0	77	0.28	0.24	2.57
			L.S.D. 5%	10	0.04	0.04	N.S.
			L.S.D. 1%	14	0.06	N.S.	

[1]All treatments received, in addition, 300 lbs. per acre of 4-12-12 at planting and 30 lbs. per acre of N as a side-dressing when corn was knee high.

long dry periods the yield advantage from deep placement was not significant. Controlled drainage and irrigation may be the solution.

LITERATURE CITED

1. Blue, W. G. and Charles F. Eno. Magnesium and lime are needed in the Suwannee Valley Area. Florida Agr. Exp. Sta. Bul. 577. 1956.
2. Carlisle, Victor W. Soil survey of Escambia County, Florida. Univ. of Fla. Agr. Exp. Sta. Series 1955, No. 8, 1960.
3. Gammon, Nathan, Jr., J. R. Henderson, R. A. Carrigan, R. E. Caldwell, R. G. Leighty, and F. B. Smith. Physical, spectrographic and chemical analyses of some virgin Florida soils. Florida Agr. Exp. Sta. Bul. 524. 1953.
4. Long, David D. "Editor" The Peanut—The Unpredictable Legume. The National Fertilizer Association, Washington, D. C. 1951.
5. Mehlich, A. Improvements in colorimetric magnesium and ammonium methods with sodium polyacrylate. A.O.A.C. 518-523. 1956.
6. Robertson, W. K., J. G. A. Fiskell, C. E. Hutton, L. G. Thompson, R. W. Lipscomb, and H. W. Lundy. Results from subsoiling and deep fertilization of corn for 2 years. Soil Sci. Soc. Am. Proc. 21: 340-346. 1957.
7. Robertson, W. K., C. E. Hutton and W. D. Hanson. Crop response to different soil fertility levels in a 5 by 5 by 5 by 2 factorial experiment: II. peanuts Soil Sci. Soc. Am. Proc. 20: 531-543. 1956.
8. Robertson, W. K., C. E. Hutton, H. W. Lundy, L. G. Thompson, and R. W. Lipscomb. Response of row crops to lime. Soil and Crop Sci. Soc. Fla. Proc. 17: 72-85. 1957.
9. Wofford, I. M., E. S. Horner, and D. E. McCloud. Plant populations, date of planting and nitrogen levels for field corn. Soil and crop Sci. Soc. Fla. Proc. 16: 352-359. 1956.

Current Status and Future Development of Research Pertaining to the Nutrient Requirements of Field Crops Growing on the Organic and Sandy Soils of Southern Florida[1]

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INTRODUCTION

Research on field crops production was initiated on organic soils in southern Florida soon after 1924 with the establishment of the Everglades Experiment Station. The earlier research was rather limited in scope until 1931 when the first herd of beef cattle was brought to the Everglades Station. At that time a more complete program of agronomic research was initiated to include studies on management programs for an anticipated beef cattle industry in an area where the forage production potential seemed limitless. About 1939 commercial beef cattle production was initiated in the Glades area, and this industry has been growing steadily since that time. Southern Florida has become one of the most extensive areas in the state for beef cattle production and dairying with land area and facilities for much more expansion. All of this has emphasized the need for research on field crops production to supply the increasing need for feeds.

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Earlier developments in livestock production on the sandy soils involved dairying along with small numbers of native beef cattle that roamed the range at will, feeding on any available indigenous foliage. The gradual improvement in livestock production on the sandy soil areas was initially brought about through the application of research contributions from experiments conducted with livestock and agronomic crops at the Main Station in Gainesville. Formal research with field crops on the sandy soils in southern Florida was initiated by the Everglades Station in 1950 with the appointment of an agronomist who was located in eastern Palm Beach County. The establishment of Indian River and Plantation Field Laboratories provided focal points for a more complete research program with field crops to supply information to the rapidly expanding beef and dairy industry on the sandy soils in southern Florida.

ORGANIC SOILS

Everglades organic soils are deficient in several minerals. Thus, the first research efforts in the production of field crops on these soils involved investigations relative to the nature and quantities of minerals needed for efficient crops production. The earliest report on some of this research was given by Allison *et al* (3) who showed the need for copper as a nutrient for crops growing on these soils. They showed further responses to applications of some of the other minor elements including manganese and zinc along with potassium. Included in the crops showing outstanding response to copper applications were corn, sorghum, sugarcane, soybeans, cowpeas, and certain clovers.

Because of the need for improved pastures, the earlier research with field crops from 1930 to 1940 emphasized pasture crops. With the introduction of improved grasses, extensive experiments were set up involving rates, methods and time of application of various major and minor elements. A bulletin by Neller and Daane (23) reported the yield and composition of grass crops in relation to fertilizer treatments. They concluded that phosphate and potash equivalent to the amounts contained in an 0-6-12 formula, at 500 pounds per acre, should be applied at least once each year to keep Dallisgrass pasture at a moderately high rate of productivity. Maximum yields of grass hay were obtained by an annual application of 500 pounds of an 0-12-24 mixture. Blaser and Boyd (4) recommended an annual application of 500 pounds of an 0-6-24 fertilizer to winter clovers in Florida. They suggested including 100 pounds per acre of 20% ammonium sulfate or other nitrogen equivalent at seeding to encourage earlier growth of the clover. They also suggested applying 50 pounds of copper sulfate, 50 pounds of manganese sulfate and 10 pounds of zinc sulfate per acre to soils that had not previously received applications of these minor elements. Neller (22) showed that fertilizer treatments had a pronounced effect on the phosphate and minor element contents of pasture forages in the Everglades, thus indicating the necessity of a careful analysis of the needs of grazing animals in determining an optimum fertilizer program. In a later publication summarizing the fertilizer needs of pastures, Allen and Kidder (1) stated that, "an initial application of 500 pounds per acre of 0-8-24 fertilizer is generally recommended on virgin peat, followed by annual applications of 300 pounds of the same analysis. After four or five years, a change to 0-12-16 at 300 pounds per acre is recommended. Initial applications of up to 50 pounds per acre of copper sulfate followed by 12

to 15 pounds annually, or about half of these amounts of copper oxide, are necessary for maximum production of most pasture grasses, and are essential for growth of others such as pangolagrass and for the health of grazing animals. MnO at 1½%, ZnO at 1.0% and B_2O_3 at 0.8% should also be included in the initial fertilizer mixture. General applications of lime or dolomite are desirable on the acid peat areas." In a more recent report, Forsee (10) has given general suggestions for routine maintenance of mineral nutrients on Everglades pastures. Soil tests are advisable in order to determine the most economical fertilization in establishing pastures on areas previously used for vegetables and other more heavily fertilized crops. Soil tests are also advisable periodically (every 4 to 6 years) for pastures which have been routinely fertilized annually in accordance with the best recommended practices.

The need for copper and other minor elements for field crops growing on organic soils was established early (3) in the history of agronomic research in southern Florida. A more thorough coverage of research with copper has been given by Forsee *et al* (12). They reported that finely ground copper oxide, as a soil corrective for copper deficiencies in crops growing on Everglades organic soils, was as efficient as copper sulfate when applied on the basis of equivalent amounts of elemental copper. Both forms of copper were equally effective either as separate applications or mixed in the fertilizer. Maximum growth was obtained with soil applications of the copper compound equivalent to 12 pounds per acre of elemental copper. A thorough discussion and review has been presented by Kretschmer (18) on forage growth and animal health as related to fertilization of Everglades pastures. His discussion included nitrogen, phosphorus, potassium, copper, manganese, zinc, boron, iron and cobalt.

Annual forages and small grains, including field corn, sorghum, sorgo and millet, have been given considerable research investigation, particularly during the last twenty years. General recommendations for field corn production are given by Green *et al.* (14). For corn on virgin organic soils they recommend 500 to 600 pounds per acre of 0-8-24 fertilizer containing 3.0% CuO, 2.0% MnO, 1.2% ZnO and 0.7% B_2O_3. Inasmuch as field corn is commonly planted following heavily fertilized vegetable crops, it is suggested that fertilizer requirements be determined on the basis of a soil test.

Green (13) and le Grand (21) recommended fertilizing sorghum, sorgo and millet at approximately the same rate as field corn. A more detailed report of sorghum production, including fertilization, is given in a recent Florida Agricultural Experiment Station Bulletin by Boyd *et al* (7).

Sugarcane, another potentially important forage crop especially adapted to organic soils production, was discussed by Bregger and Kidder (9). They suggested on newly cultivated muck, the application of 300 pounds per acre of 0-10-45 fertilizer containing 0.3% CuO, 0.4% MnO, 0.2% ZnO and 0.15% B_2O_3, applied in the furrows before the seed cane is laid. In the spring when the cane completely shades the middles, 200 pounds per acre of 0-10-45 fertilizer should be applied as a sidedress. For subsequent ratoon crops, 500 pounds per acre of 0-10-45 should be applied annually as soon as practicable after cutting. In general minor elements are omitted from the fertilizer for ratoon crops.

SANDY SOILS

The sandy soils of southern Florida are usually acid in reaction, and most crops show a positive response to liming. High rainfall intensity causes

considerable leaching of most plant nutrients. Phosphorus is relatively more stable than nitrogen and the bases, and may accumulate with repeated applications of mixed fertilizer. Field corn, sorghum and pasture grasses are the major crops upon which research on nutrient requirements has been done. Of these crops, pastures have been examined in greatest detail.

Boyd (6) reported highest forage yields of St. Augustinegrass on Davie fine sand from 3,000 pounds per acre of 16-6-6 fertilizer applied three times a year at the rate of 1,000 pounds per application. Boyd[3] also reported nitrogen at 240 pounds per acre produced as much forage in four applications as the same amount of nitrogen applied in eight separate applications. Similarly, nitrogen at 120 pounds per acre produced as much forage from two applications as the same amount of nitrogen split into four applications. Early September fertilization of St. Augustinegrass, pangolagrass and Pensacola bahiagrass produced the greatest yields during the winter months. Refertilization of these grasses was necessary in early May or June to give satisfactory summer production. Kretschmer (18) has described the calcium, magnesium, potassium, phosphorus and nitrogen requirements of pasture grasses on sandy soils, and the relationship of such treatments to forage growth and animal health. He suggested the use of lime and rock phosphate along with a yearly application of 300 to 500 pounds per acre of 6-6-6 fertilizer plus minor elements sufficient to supply the equivalent of 15 pounds copper sulfate, 15 pounds manganese sulfate, 15 pounds ferrous sulfate, 10 pounds zinc sulfate and 10 pounds borax per acre. In addition, he suggested two top dressings consisting of 50 pounds N and 50 pounds K_2O per acre.

Earlier recommendations were made by Blaser and Boyd (4) for winter clovers. More recent experiments conducted in considerable detail by Kretschmer (20, 17), indicated that the early growth of clover was influenced primarily by the supply of available phosphorus. For instance, high calcic lime at 2,000 pounds per acre depressed the rate of growth unless larger rates of phosphorus were used. Applications of one ton of high calcic lime required at least 100 pounds of P_2O_5 per acre to insure maximum growth. The need for lime became more apparent after the initial growth stage. Rock phosphate applications of 2,000 pounds per acre produced good clover growth. Initial clover growth was stimulated markedly by applications of 200 to 250 pounds of ammoniated superphosphate per acre. Surface-applied lime was equally as effective as the same amount incorporated into the soil to depths of 4 to 8 inches. For maximum yields of clover-pangolagrass mixtures the pH of the soil should be above 5.0. Boyd *et al.* (8) obtained greatest response of legume-grass mixtures to phosphates when used along with dolomitic limestone. He found that Hubam sweetclover and Hairy Peruvian alfalfa were particularly responsive to rock phosphate on Davie fine sand with a pH of 5.8.

As with all field crops on sandy soils, the amount of fertilizer required for field corn is dependent on the rainfall distribution during the growth of the crop. Field corn production, including fertilization, has been reported in some detail by Green *et al* (14). Boyd (5) suggests at planting time 600 to 800 pounds per acre of 8-8-8 fertilizer containing 1.0% each of CuO and MnO. Sidedressed applications of 15-0-14 should be applied at such frequency and in such quantity as best judgment of the season

[3]Unpublished data.

would indicate. Normally, two applications may be sufficient. For corn planted in September, lower rates of fertilizer should be used at planting time, but with heavier sidedressed applications as the drier months of the season approach. Field corn can be economically produced following vegetables. Forsee and Hayslip (11) reported maximum yields of field corn following unstaked tomatoes from an application of 120 pounds per acre of soluble nitrogen applied as two or more sidedressings. Further experiments by Kretschmer and Hayslip (19) confirmed this suggested nitrogen application rate, with one-third to one-half the nitrogen applied at planting time and the remainder when the corn was about knee high.

Sorghum, as grown is south Florida, can be harvested successfully as a ratoon as well as a plant crop. Boyd *et al* (7) reported that the highest forage yields have been obtained from 1,000 pounds 8-8-8 or 8-12-12 fertilizers. Highest grain yields have been obtained from 4-12-12 fertilizer containing 1.0% each of CuO and MnO. Fertilizers are applied at the time of seeding and at the time of the first cultivation of each ratoon.

Sugarcane is another potential forage crop for sandy soils. Bregger and Kidder (9) recommended fertilization at planting with 300 pounds per acre of 4-8-4 fertilizer containing 2.0% MgO, 0.3% CuO, 0.4% MnO, 0.2% ZnO, and 0.15% B_2O_3. In the spring before closing in, the sugarcane should be sidedressed with 500 pounds per acre of 14-0-15. They suggested that 40% of the nitrogen be derived from organic sources.

FUTURE RESEARCH DEVELOPMENT

Although basic data have been accumulated and recommendations are available for most field crops normally grown in southern Florida, the experiments have been conducted under, and recommendations made for, the more simple types of management involving beef cattle on the range and the harvesting of an annual crop for forage or grain. More intensive management practices and also new crops will come into the picture and higher yielding varieties of existing crops will no doubt be found. These will require further investigations on their nutrient requirements. Management practices affording higher yields will necessitate heavier and more frequent fertilization with the attendant results of imbalance among nutrients normally applied, and the possible discovery of the need of mineral elements as yet not considered necessary for soil application. The problem of mineral imbalance under intensive management can become especially noticeable on organic soils from which there is little loss of nutrients by leaching.

Management practices which allow more intensive utilization of organic soils are already under investigation. Research with beef cattle has emphasized the need for winter forage in order to support a high maintenance level for the best quality beef. The high cost of land prohibits the setting aside of extensive areas for the production of summer forages and grain crops on a one-crop-per-year basis. This means management practices which allow year-round utilization of every acre at its maximum productivity either of perennial or annual crops. The harvesting of excess summer forage and its preservation as silage has been investigated by Allen *et al* (2). Another idea being pursued by these same investigators is the interplanting of winter annuals with perennial pastures for winter utilization. Both of these practices will require changes in the amount and frequency of fertilization.

The normally high moisture content of Everglades forages practically precludes the idea of artificial drying of such crops for storage as winter feeds because of the high costs involved. The frequent rains and high humidities during the summer months, the time of maximum yields of perennial grasses and most annual forages, practically eliminate the possibility of hay making. Randolph *et al* (24) have proposed an apparently economical method of mechanically dewatering such forages as a preliminary step to fresh feeding, silage preparation or artificially dehydrating for storage. Further research should solve the problems involved in this proposed process, and may result in the harvesting of extensive tonnages of feeds for utilization by both beef and dairy animals. In order to be economical, such production would necessarily be on an intensive basis which would require the most efficient management and utilization of applied nutrients. The development of this and other procedures for processing the potential field crops production of the Everglades will no doubt introduce many problems of fertilization which can be solved only through research.

Because of the rapid increase in land costs, the management of livestock on the sandy soils will advance from the present range management to a more intensive type. This is already true with the dairy industry where feed deficiencies are corrected by supplementing with commercial feeds. At present the margin between costs and sales is sufficient to allow such a procedure. However, any substantial reduction in this margin will no doubt increase the need for the economical production of more home-grown feeds.

In addition to the production potential on organic soils, many acres of sandy soils are under sufficiently good water control to allow intensive management. This is demonstrated by the large acreage of vegetable crops produced on these soils. In fact, reasonable amounts of forage may be produced in areas where vegetables are grown in rotation with field crops. This has certain advantages for vegetable production as shown by Hayslip and Kretschmer (16). Such a rotation, however, introduces problems that will change field crops management in order to fit in with the requirements for vegetables. For example, much of the experimental work to date involving intensive production of pastures on sandy soils includes clovers as a part of the mixture. Some of the recommended fertility programs for such pastures are based on the presence of clover to augment the nitrogen supply. Hayslip and Stall (15) have shown that a preceding clover planting increases the incidence of soil rot of tomato fruit. Unless some chemical or varietal control for this severe disease can be obtained, it may not be advisable to include clover in such a rotation schedule. Winchester (25) has demonstrated that pure stands of pangolagrass may reduce the root-knot nematode, *Meloidogyne incognita acrita*, in a following crop of vegetables. Management practices designed to fulfill the specific requirements of any crop included in the rotation will require a thorough review in order to effectively and efficiently meet the fertilizer requirements of each crop. Whether or not the area follows a pattern of diversified farming involving rotation of field crops with vegetables; or whether field crops production is restricted to the larger economic ranching and dairy units, or to producers of field crops to be sold to ranchers or dairymen, a great deal more basic information than is now available will be needed in order to recommend effective fertilizer programs.

In future studies of the nutrient requirements of field crops more at-

tention must necessarily be given to the value of crop residues including top growth, roots and decomposed sods. How much of the plant nutrient requirements can be supplied by such residues? Water-plant relationships and plant nutrient requirements need further study. More definite information is needed on the amount and intensity of rainfall effects on leaching. The need for such information is especially true for the sandy soils and must be differentially obtained, especially as it relates to the principal soil types.

Present information shows that lime, rock phosphate and minor elements have a place in the plant nutrient program for field crops on sandy soils. Specific quantitative information is lacking, however, for different crops and different soil conditions. The plant nutrient requirements also need to be studied in relation to fertilizer placement and in relation to differing plant populations.

CONCLUSIONS

Basic fertilizer data are presently available from previous and current research conducted with field crops. These data are extensive and are sufficient to cover a substantial part of the present requirements for information in southern Florida. Further research, however, is needed to correlate soil, weather, crop and cultural effects with the most efficient use of these plant nutrients. These needs will be especially intensified as management practices become more complicated in order to utilize every acre to its maximum in the production of the highest quality agricultural commodities.

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LITERATURE CITED

1. Allen, R. J., Jr. and R. W. Kidder. Pastures on Florida's peats and mucks. Soil and Crop Sci. Soc. Fla. Proc. 12: 101-104. 1952.
2. Allen, R. J., Jr., D. W. Beardsley and D. S. Harrison. Winter feed on Everglades pasture. Soil and Crop Sci. Soc. Fla. Proc. 15: 191-197. 1955.
3. Allison, R. V., O. C. Bryan and J. H. Hunter. The stimulation of plant response on the raw peat soils of the Florida Everglades through the use of copper sulphate and other chemicals. Florida Agr. Exp. Sta. Bul. 190. 1927.
4. Blaser, R. E. and F. T. Boyd. Winter clover pastures for peninsular Florida. Florida Agr. Exp. Sta. Bul. 351. 1940.
5. Boyd, F. T. Cultural practices useful in growing field corn on south Florida sandy soils. Soil and Crop Sci. Soc. Fla. Proc. 17: 226-230. 1957.
6. Boyd, F. T. Nitrogen fertilization of St. Augustinegrass grown on Davie fine sand. Soil and Crop Sci. Soc. Fla. Proc. 15: 82-85. 1955.
7. Boyd, F. T., V. E. Green, Jr. and H. L. Chapman, Jr. Production of sorghum forage and grain as feed for dairy and beef cattle in south Florida. Florida Agr. Exp. Sta. Bul. 628. 1961.
8. Boyd, F. T., A. E. Kretschmer, Jr. and W. T. Forsee, Jr. Soil fertility investigations under field and greenhouse conditions. Florida Agr. Exp. Sta. Ann. Rpt. 1954: 247-248.

9. Bregger, T. and R. W. Kidder. Growing sugarcane for forage. Florida Agr. Exp. Sta. Circ. S-117. 1959.
10. Forsee, W. T., Jr. Suggestions for pasture fertilization. Everglades Sta. Mimeo Rpt. 61-3. 1960.
11. Forsee, W. T., Jr. and N. C. Hayslip. Fertility requirements of field corn grown on sandy soils following a fall crop of unstaked tomatoes. Florida State Hort. Soc. Proc. 66: 148-153. 1953.
12. Forsee, W. T., Jr., T. C. Erwin and A. E. Kretschmer, Jr. Copper oxide as a source of fertilizer copper for plants growing on Everglades organic soils. Florida Agr. Exp. Sta. Bul. 552. 1954.
13. Green, V. E., Jr. Sorghum, millet and field corn forage crop tests. Everglades Sta. Mimeo Rpt. 60-1. 1959.
14. Green, V. E., Jr., W. T. Forsee, Jr., W. H. Thames, Jr. and F. T. Boyd. Field corn production in South Florida. Florida Agr. Exp. Sta. Bul. 582. 1957.
15. Hayslip, N. C. and R. E. Stall. Severity of tomato soil-rot caused by *Rhizoctonia solani* as influenced by former pasture crops. Plant Disease Reporter 43: 818-820. 1959.
16. Hayslip, N. C., A. E. Kretschmer, Jr., E. M. Hodges and D. W. Jones. Pasture-Vegetable rotation aids both. Sunshine State Agr. Res. Rept. 1 (3): 4-5. 1956.
17. Kretschmer, A. E., Jr. Growth of Louisiana S1 white clover seedlings as influenced by soil additions of lime and phosphate. Soil and Crop Sci. Soc. Fla. Proc. 18: 136-149. 1958.
18. Kretschmer, A. E., Jr. Pasture fertilization in the Everglades area as related to forage growth and animal health. Everglades Sta. Mimeo Rpt. 55-9. 1955.
19. Kretschmer, A. E., Jr. and N. C. Hayslip. Plant field corn after vegetables. Sunshine State Agr. Res. Rpt. 2 (1): 11. 1957.
20. Kretschmer, A. E., Jr., N. C. Hayslip and C. T. Ozaki. Liming experiments and observations with white Dutch clover on Immokalee fine sand. Soil and Crop Sci. Soc. Fla. Proc. 17:274-286. 1957.
21. le Grand, F. Sorgo varieties for forage use on Everglades soils. Everglades Sta. Mimeo Rpt. 60-2. 1959.
22. Neller, J. R. Factors affecting composition of Everglades grasses and legumes. Florida Agr. Exp. Sta. Bul. 403. 1944.
23. Neller, J. R. and A. Daane. Yield and composition of Everglades grass crops in relation to fertilizer treatment. Florida Agr. Exp. Sta. Bul. 338. 1939.
24. Randolph, J. W., L. Rivera-Brenes, J. P. Winfree and V. E. Green, Jr. Mechanical dewatering as a potential means for improving the supply of quality animal feeds in the tropics and sub-tropics. Soil and Crop Sci. Soc. Fla. Proc. 18: 97-105. 1958.
25. Winchester, J. A. and N. C. Hayslip. The effect of land management practices on the root-knot nematode, *Meloidogyne incognita acrita*, in South Florida. Florida State Hort. Soc. Proc. 73:100-104. 1960. (In Press).

Developments in Legume Inoculation[1]

LEWIS W. ERDMAN[2]

In the invitation to present a paper before your society it was suggested that a superior coverage of legume inoculation, current and future, was the wish of your program committee. On account of the brief time alloted for this discussion, it may be well to limit the area of research to our studies on *Rhizobium* in the Beltsville Soil-Plant Laboratory.

BACTERIAL INDUCED CHLOROSIS IN SOYBEANS

During the past five years we have been intrigued by the myriad of research problems emanating from the discovery of a *Rhizobium japonicum* that has strayed from its normal function, and in some unknown manner is capable of inducing chlorosis in soybean plants. This work is in cooperation with the Crops Research Division and several publications have been issued (1), (2), (3), (4), (5), (6) and (7). At first we thought that this phenomenon was restricted to the Lee and Ogden varieties. Further investigation showed that if certain definite conditions prevailed, many more varieties were susceptible, and, in fact, of the 200 varieties tested only 16 have proved to be resistant. We have isolated a number of strains of this organism, some are more virulent than others, and some show varying degrees of compatibility when grown in mixtures of normal strains.

CHARACTERISTICS OF CHLOROTIC PLANTS

Certain facts have been established based upon outstanding characteristics of chlorotic plants and their nodules. 1. At the second or third trifoliate leaf there is a blockage of normal photosynthesis—the plants continue to grow, the first two or three leaves remain a deep green color, but the new leaves show a definite chlorosis pattern. 2. Nodules produced by chlorosis-inducing strains are highly effective, large, clustered around the tap root and red inside. They are definitely not parasitic. 3. Aqueous extracts of these nodules contain a chemical compound, presumably produced by the *Rhizobium*, which is highly soluble, heat stabile—can be sterilized, and will retain its ability to produce chlorosis for months when stored at ordinary temperatures. An unusual assay has been developed, whereby a sorghum seedling placed in a crushed nodule suspension will show chlorosis in the first true leaf if the compound is present. This promises to be a tool of far reaching importance to study strain competition interrelationships and to identify strains of *R. japonicum*.

COMPETITION BETWEEN BACTERIAL STRAINS

Using the sorghum seedling technique, competition between genotypes of *R. japonicum* was studied with chlorosis-inducing strains Nos. 76 and

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[1]Contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, USDA.

[2]Principal Bacteriologist, USDA, Beltsville, Maryland.

94 to facilitate identification of strains recovered from nodules of soybean plants. The chlorosis-inducing strains were individually mixed in varying proportions with each of 9 normal strains and the mixtures were used as inoculants on the Hawkeye and Lee varieties. The plants were grown in the greenhouse using sand cultures.

Technique studies indicated that with rare exceptions a single nodule contained only one bacterial strain and that chlorosis of sorghum seedlings produced by a water extract of a nodule was a reliable indication that the nodule contained a chlorosis-inducing strain. Some results of this study are given in Table 1.

Strain No. 76 had a pronounced competitive advantage over all normal strains regardless of the proportions of the strain in the mixtures. As little as 1.1% of No. 76 in the mixture with strain No. 38 (a normal strain) caused 85% of the nodules on the plants under study. Strains 31 and 71 were more competitive against 76 than were the other normal strains. Chlorosis-inducing strain No. 94 was much less competitive against 8 of the 9 normal strains than was No. 76. The extent of chlorosis of the soybean plants gave a rough estimate of the competitive relationship between strains.

TABLE 1.—MEAN PERCENT CHLOROTIC PLANTS AND CHLOROSIS SCORE OF SOYBEAN PLANTS INOCULATED WITH VARIOUS MIXTURES OF CHLOROSIS-INDUCING AND NORMAL STRAINS.[1]

	Mixture with strain 76			Mixture with strain 94		
Normal strain	% of 76 in mixture	% of plants chlorotic	Maximum chlorosis score[2]	% of 94 in mixture	% of plants chlorotic	Maximum chlorosis score
28	3.7	100	2.8	2.7	100	3.2
	55	100	3.4	47	100	3.9
31	1.3	22	0.4	0.9	0	0
	29	95	1.8	23	0	0
38	1.1	100	2.4	0.8	16	0.2
	27	100	3.1	21	16	0.2
48	1.7	100	2.0	1.2	16	0.1
	36	100	2.6	29	61	0.8
60	1.1	100	1.6	0.8	0	0
	26	100	2.6	20	11	0.2
62	0.9	100	2.8	0.6	22	0.2
	22	100	2.6	17	66	0.8
71	0.8	44	0.2	0.6	0	0
	20	100	2.2	16	28	0.1
104	1.2	100	2.5	0.8	62	1.0
	28	100	2.8	22	100	2.6
105	1.4	100	3.1	1.0	62	1.0
	32	100	3.4	25	100	3.0
	100	100	3.5	100	100	4.2

[1]Mean of three replications of each of the varieties Hawkeye and Lee.
[2]Chlorosis scored from 1 to 5 with 1 indicating light chlorosis and 5 severe chlorosis.

SEROLOGICAL STUDIES

Since the chlorosis factor is so limited and so far as we know is restricted to the soybean plant, serological techniques are being used as a means of identifying rhizobial strains which have been used to inoculate legume plants. Soybeans, peanuts and alfalfa are the plants under study. This method has been widely used in Australia and England but only to a limited extent in the United States. Obviously this method has limitations because it is possible to have a chlorotic and a non-chlorotic strain give identical reactions with the same serum. This is particularly true with the more primitive soybean and peanut organisms, when compared with the highly developed *R. trifolii* strains. However, by cross absorption we have hopes of identifying individual strains, and thereby gain more knowledge on the competitive influence of strains added in the inoculum on those naturally present in soils.

GENETIC STUDIES WITH THE NITROGEN FIXING ORGANISMS

We are attempting to obtain more efficient nitrogen-fixing microorganisms through genetic techniques making use especially of the transduction theory and the possible existence of temperate phages among the rhizobia. This research is essentially fundamental and belongs to the typical pioneer laboratory. Progress has been extremely slow but it is evident from the work so far that one of the following situations prevails:

1. Temperate strains of rhizobiophage (bacterial strains which carry a prophage, i.e., the genetic determinant for producing phage) are extremely rare, a situation which we consider most unlikely in view of what we know about the rhizobia and by drawing analogies with other organisms.
2. Nearly all rhizobial strains are infected with prophages closely enough related to give immunity. In this situation, the finding of a suitable indicator strain is precluded.
3. The temperate relationship is so highly developed within those strains where it occurs that only extremely weak lysis is obtained.
4. Other subtle unknown factors enter into the relationship.

DEVELOPMENT OF MORE EFFECTIVE LEGUME INOCULATION

During the past year and a half 174 nodule specimens were received from 25 actively participating missions receiving financial aid from I.C.A. One hundred and fourteen pure culture strains of *Rhizobium*, representing fifty different legume species have been isolated from these nodule specimens. Growth chamber and greenhouse experiments to determine the nitrogen-fixing capacity were completed for 150 A.R.S. stock cultures and most of the 114 strains of *Rhizobium* isolated from the I.C.A. nodule specimens. A total of 300 humus cultures prepared from superior strains were sent to some 25 missions to be field tested. It is felt that these investigations will lead to the development of more effective strains of *Rhizobium* and prove to be valuable in strengthening or supplementing technical assistance programs of I.C.A. missions in foreign countries.

PRE-INOCULATED LEGUME SEEDS

In the early thirties attempts were made to inoculate legume seeds in dealers' warehouses, and sell pre-inoculated seed to farmers. This program, however, proved unsuccessful and was soon abandoned. A major break-through in legume inoculation practice was announced by Northrup-King and company, in November 1958 when they offered to the seed trade "Noculized"[3] alfalfa seed (8). This new "Noculized" process claimed at least five important advantages over regular inoculation. Since it was introduced, at least five other processes for pre-inoculating legume seeds have been offered to the seed trade. These include "Vicoat" by the Nitragin Company, Inc.; "Micro guard," Kalo Inoculant Co.; "Dormal" Agricultural Laboratories, Inc.; "Nitro-Charged," Teweles Seed Company; "Pre-inoc," Nodogen Laboratories and Urbana Humus Inoculator containing 109, the Urbana Laboratories.

The main objective of all of these processes is to pre-inoculate legume seeds in the warehouses, processing plants or at the inoculant producer's home plant, and to be able to hold them, if necessary, from three to six months and possibly longer, before they are planted by the farmer.

RESULTS OF 1959 GREENHOUSE TESTS

Results of tests made on 35 samples of pre-inoculated alfalfa seeds sent in by seedsmen and to Agricultural Marketing Service showed that every sample produced satisfactory inoculation in the first test that we made in February or March. Most of these seeds were "noculized" in early January, 1959. In July, these same samples were again tested—some had viable bacteria after keeping this length of time stored in ordinary seed envelopes in the laboratory. However, the majority of samples failed to show satisfactory inoculation and consequently it would appear that five or six months would be the limit for a safe recommendation.

RESULTS OF 1960 GREENHOUSE TESTS

In the spring of 1960, a total of 76 pre-inoculated seed samples were tested in plant growth rooms and greenhouses. These samples were obtained directly from four licensed processors and from three producers of legume seed inoculants. The tests were designed to show the presence and effectiveness of the rhizobia on the pre-inoculated seed at the time of planting. A summary of the results showed that 43 samples gave satisfactory inoculation under the conditions of our tests when they were planted within a month or six weeks after treatment. Twenty-three samples failed to produce any inoculation benefits at the first planting. Results from the remaining samples were inconclusive at the first planting. Twenty-eight samples were distributed to agronomists at eastern and southeastern experiment stations and in California for field planting. For sundry reasons, we did not get any conclusive results from field tests.

It was not possible to test a large number of samples at successive monthly intervals. In general, however, most of the samples which were planted on May 26, 1960 failed to show any inoculation benefits. Some few samples

[3]Mention of proprietary products does not constitute either their recommendation or their endorsement by the United States Department of Agriculture.

planted on June 23 still contained seeds which carried viable and effective nitrogen-fixing legume bacteria.

EFFECT OF TEMPERATURE ON SURVIVAL OF RHIZOBIUM

Preliminary studies on survival of *Rhizobium* on pre-inoculated seed showed that temperature is extremely important. Some results are given in Table 2.

Using another technique, data indicated that loss of viability was greater at high seed moisture (13-14%) than at low seed moisture (6-7%). Viability also decreased with decrease in temperature over a range of 25° C. to 5° C. This parallels readings made on seed germination studies.

DISCUSSION OF PRE-INOCULATION RESULTS

Results of our greenhouse tests are encouraging. If the bacteria remain alive and active in sufficient numbers to produce effective inoculation after three or four months, it may be possible, through further research, to extend their longevity. Techniques used in the lyophilization of the organisms offer possibilities and according to reports one of the "processes" which will be offered to the seed trade this coming year will make use of the freeze-dry principle. Every-one appreciates the urgent need for more intensive research on this pre-inoculation seed problem, and especially is this true with the producers of the legume inoculants. These companies have been reluctant to recommend pre-inoculated seeds for the southeastern United States, because of the temperature-humidity relations. We have a feeling that the most pressing problems will be solved, and that this practice may be a solution to your inoculation problems.

The Agricultural Research Service, and more specifically the ESWMRB is keenly interested in the research aspects of the pre-inoculation concept. We would like to know:

1. What has happened to the *Rhizobium* which now enables it to live in a dry state up to 90 days or longer?
2. Is it the specific "process" that has brought about this change?
3. Is it the special adhesive or carrier used with or in the inoculant to treat the seeds?
4. Has the *Rhizobium* undergone genetic changes—does it really produce spores?
5. If it has some other form of resting stage, what is the nature of it and how can it be proven?
6. How long can the bacteria live on or within the legume seed?

TABLE 2.—DATA ON SURVIVAL OF RHIZOBIA ON PRE-INOCULATED SEED STORED AT DIFFERENT TEMPERATURES.

	Number of rhizobia per seed		
		After 21 weeks	
	Initially	At 5° C.	At 25° C.
Alfalfa	10,000	3200	13
Red clover	10,000	102	5

These are just a few questions that need to be answered. We could continue asking other questions that have arisen since this practice has come into use. We are confident that only through rigid and controlled research will the answers be found.

LITERATURE CITED

1. Erdman, Lewis W., Herbert W. Johnson, and Francis Clark. A bacterial-induced chlorosis in the Lee soybean. Plant Disease Reporter. Vol. 40, No. 7, p. 646. 1956.
2. Erdman, Lewis W., Herbert W. Johnson, and Francis Clark. Varietal response of soybeans to a bacterial-induced chlorosis. Agron. Jour. 49:267-271. 1957.
3. Johnson, Herbert W., Ura Mae Means, and Francis E. Clark. Factors affecting the expression of bacterial-induced chlorosis of soybeans. Agron. Jour. 50:571-574. 1958.
4. Johnson, Herbert W. and Francis E. Clark. Role of root nodule in the bacterial-induced chlorosis of soybeans. Soil Sci. Soc. Amer. Proc. 22: 527-528. 1958.
5. Johnson, Herbert W., Ura Mae Means, and Francis E. Clark. Responses of seedlings to extracts of soybean nodules bearing selected strains of *Rhizobium japonicum*. Nature. Vol. 183:308-309. 1959.
6. Johnson, Herbert W. and Ura Mae Means. Interaction between genotypes of soybeans and genotypes of nodulating bacteria. Agron. Jour. 52:651-654. 1960.
7. Means, Ura Mae, Herbert W. Johnson, and Lewis W. Erdman. Competition between bacterial strains effecting nodulation in soybeans. Soil Sci. Soc. Amer. Proc. 25:105-108. 1961.
8. Porter, Frederic E., Vernon W. McAlpine and Howard E. Kaerwer, Jr. Seed impregnation including bacterial and vacuum treatment. United States Patent Office, Patent Number 2,932, 128, April 12. 1960.

Water Control as a Limiting Factor in Field Crop Production in Florida

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INTRODUCTION

The end product of water control measures, insofar as field crop production is concerned, is to control erosion and the level of moisture in the soil. Any structure, or soil management practice, that has a direct or indirect affect on the availability of soil moisture may be called a water control measure. Surface and sub-surface drainage, surface and sub-surface irrigation, terracing, contour cultivation, mulching and cultural practices affecting soil structure at the surface and below are a partial list of water control measures used in Florida. The first two named are probably the most widely practiced, when considered on a state wide basis, and will be treated in detail.

SOIL MOISTURE AND PLANT GROWTH

Soil moisture is an essential requirement for plant growth. Water control, by the works of man or nature, has a substantial effect on the soil moisture level at any particular time. Plants, in general, are reasonably tolerant to wide variations in soil moisture levels, however, little is known

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about plant responses to specific levels of soil moisture. Scientists are in general agreement that the growth of plants reflect the rate at which energy is used to remove water from the soil to supply their needs.

Taylor (13) points out in the 1957 Yearbook of Agriculture that we should remember the following factors about the use of moisture by plants:

a. Proper balance of moisture in the root zone of growing plants is necessary for healthy, vigorous growth.

b. Insufficient aeration will limit growth and the uptake of water if soil is too wet.

c. As soil dries out, the plant is placed under increasing stress until the rate that water can move to the plant root and be absorbed is no longer fast enough to prevent retarded growth and decreased vegetative yields.

d. During dry, hot weather, the limiting stress in plants might occur at relatively low soil moisture tensions of one atmosphere or less.

e. During cool, humid weather, tensions might become four atmospheres or higher before plant growth is retarded.

f. Limiting plant stress is reached at lower soil moisture tensions in soil containing few roots than in soil with large numbers of roots.

Richards (11) has stated that the available supply of soil moisture is usually a major aspect of soil management. It may dominate crop selection, time and rate of planting, tillage operations, weed control measures and programs of fertilization.

In Florida, if other factors are favorable, deficiency of soil moisture may limit crop growth more often than is generally realized. The possibility of a significant deficiency depends on the crop and the soil as well as the climate. Studies of evapotranspiration in relation to climate indicate that yield-depressing droughts occur with almost statistical regularity in Florida, even though the average precipitation during the cropping season may exceed the total amount needed by the crop.

An analysis of the crop-water deficit at Gainesville for one of the driest and one of the wettest years was reported by McCloud (7) in 1955. Over 73 inches of rain was recorded for the wet year. Evapotranspiration computed from mean daily temperatures and the formula[3] amounted to over 70 inches for the year. With a two-inch plant-soil storage, the crop-water deficit amounted to almost 18 inches even in the record wet year. A percolate of 20 inches occurred. Conversely, for one of the driest years on record there was only 36 inches of rainfall. Since it was slightly warmer than the wet year, evapotranspiration was a little over 72 inches. A crop water deficit was over twice as large as for the wet year. Percolation, as would be expected, decreased to about four inches.

Excess water, as does drought, lowers the growth and use of water by most agricultural crops. Plant roots need to be aerated so that the waste carbon dioxide produced by the roots can be dispelled and replaced by oxygen. Whenever flooding, waterlogging or compaction stops this process the rate of moisture uptake is retarded, and the plants may wilt, plant growth will cease, and the plants will die if the condition continues long enough.

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[3]Potential daily water-use KWT^{-23}, $K = 0.01$, $W = 1.07$, T - Mean Temperature °F.

TABLE 1.—PLANT-WATER STORAGE RESERVOIR FOR SEVERAL CROPS AND SOILS.

Crop	Soil Type	Effective Depth of Soil, Inches	Total Available Moisture Capacity, Inches
Citrus	Lakeland sand	54	2.57
Corn	Norfolk loamy fine sand	27	2.93
Shade Tobacco	Orangeburg fine sandy loam	15	1.44
Flue-cured Tobacco	Blanton sand	21	1.26
Radishes	Ft. Meade loamy fine sand	12	0.92

CROP RESPONSE

Water control is an absolute requirement for some crops grown at certain locations in Florida. The absence of water control measures means the absence of agricultural production where certain climatic conditions, soils and crops appear in combination. Optimum water control measures make possible optimum crop growth. This is also true for other factors contributing to plant growth; so a realistic evaluation of water control as a limiting factor in field crop production may be obtained from a review of some typical crop responses to water control practices.

Many determinations of crop response to irrigation have been made in Florida, both under experimental and field conditions. It was concluded from experiments at Gainesville (10) that when irrigation is used properly, the yield of the cured tobacco can be increased 35 to 40% and quality improved 5 to 13% on the average. Marshall and Myers (9) found in a three year study at Hague, Florida that pangolagrass-white clover pastures produced 21.6% more TDN during the clover season and 9.1% more TDN during the grass season than non-irrigated pastures. They also reported grazing was started an average of 14 days earlier and a more uniform carrying capacity of cattle was maintained on irrigated pastures. Hodges *et al.* (3) at the Range Cattle Station reported the seventh consecutive crop of white clover was produced in 1956 on a 4-acre sprinkler-irrigated pasture. Jamison (5) reported from research conducted at Gainesville that sprinkler irrigation of fourteen crops of vegetables resulted in increased yields and better quality in most instances. During the summer of 1955 a pilot experiment was conducted at Gainesville by McCloud *et al.* (7) to measure crop response to irrigation on four field crops, corn, peanuts, soybeans and pearlmillet. Corn yields were increased by 87% and peanut yields were slightly decreased. Soybeans and pearlmillet yields were slightly increased. Various levels of nitrogen and phosphorus were studied with and without irrigation by Lutrick and Hutton (6) at the West Florida Station. They reported that in 1955 irrigation increased yield of corn about 30 bushels per acre.

Many of these reports of investigations were made to explore the possibilities of irrigation under local conditions. Consequently, the data may have only limited application. Nevertheless, this backlog of crop response data coupled with the known probability of drought occurrence is adequate to plan a profitable irrigation program for Florida.

There are a relatively small number of research reports furnishing data on field crop responses to drainage practices. In Florida, drainage measures are undertaken primarily to insure agricultural production rather than to gain a level of response such as might be obtained from irrigation or fertilization. Preliminary findings by the USDA ARS Field Laboratory, Ft. Lauderdale, have shown that under sub-irrigation and drainage, St. Augustinegrass on medium fine sand will yield equally as well when the water table is held at 12 or 36 inches below ground surface, irrigation requirements are increased 30% and leaching of plant nutrients is increased 10%, as compared to a 36-inch water table. Increase in incidence of plant disease has been attributed to too much water. In preliminary work on field corn at Plantation Field Laboratory, it has been shown that water use will range from .13 to .33 inches per day with an average of .27 inches per day. Best yields of corn were obtained at water table depths of 18 to 24 inches. Water conservation studies on the Rockdale soils of the Homestead area by Gallatin (1) show that it is possible by early pumping, to get land ready for plowing and planting two to three weeks earlier than adjacent areas not under water control. Also, there was no damage to crops in the water-controlled plot area, but in adjacent fields tomatoes and beans suffered 25 to 100% damage. Stevens *et al.* (12) found in an experiment to test submersion damage to crops that bush beans and peppers grown in sand and submerged in water to a depth of 1 inch above the soil surface showed permanent injury from submersion periods of 36 hours or more. Hunziker (4) reported that a tile drainage installation for citrus in Indian River County is effectively controlling the water table. While two unusually heavy concentrations of rain has raised the water table to within 18 inches of the bed crowns, water table recession has been sufficiently rapid (10 inches in first 24 hours) to prevent damage to root systems.

In the organic soils it has been shown by Harrison (2) that by continuous pumping immediately before and during rainstorms that the water table drawdown is approximately 8.44 inches per 24 hours for 2.5-inch rainfalls and 10.88 inches per 24 hours for 1-inch rainfalls.

SYSTEMS FOR WATER CONTROL

The major systems for soil moisture control may be classified according to function as either an irrigation, drainage or water control system. Methods of applying irrigation water to the land are numerous although all are not applicable to a given set of conditions and no method is applicable to all conditions. The choice of a method of application depends on the climate, soil characteristics, topography of land, water supply, growth characteristics of crop, potential value of crop and labor. Each of these must be given consideration before choosing a method of application. For discussion, it is convenient to divide the methods into two classes, surface and sub-surface irrigation. The common methods of surface irrigation in Florida are the furrow and sprinkler method.

The furrow method utilizes the furrows between the crop rows for distribution of irrigation water over the field. Water is brought to the high side of the field in head ditch or pipe line and metered so as to flow down the furrows infiltering the soil profile as the stream advances. This method is best adaptable to medium to moderately heavy textured soils.

Sprinkler irrigation is a method of applying water above the crop in the form of a spray somewhat resembling rainfall. There are four methods

of sprinkling, each using a different type of equipment, but all being dependent on the development of pressure in the distribution system. The methods are perforated pipe, oscillating sprinkler, gate sprinkler and rotary springler. Sprinkler irrigation systems are adapted to all soil types and topography and do not require special land preparation. The major disadvantage of the system is the relatively high fixed and operating cost.

Drainage is the removal of surplus water from the land surface or from below the surface to influence the level of moisture in the soil. A drainage system is a facility to collect the surplus water and then conduct it away from the field or farm. A system may be regular or random and consists of any or all of the following type drains: ditches, rows, terraces, natural water course, tile and mole.

A water control system is composed of any or all of the types of drains used for drainage and is designed to serve the dual purpose of removing excess water from the land and adding water to the soil. The object of a water control system is to maintain the soil moisture level at an optimum by drainage and irrigation according to needs.

ECONOMICS OF WATER CONTROL

Water control as a limiting factor in field crop production, in the final analysis, is dependent upon the economics of producing crops with and without it. Crop response to water control treatment runs the scale from no production (crop failure) to the largest yields on record. Costs of controlling the soil moisture level are variable. They are equally as variable as crop response to water control measures. Sprinkler irrigation costs in Florida vary between \$1.25 and \$3.50 per acre inch of water applied and the cost of irrigation through water control systems varies between \$0.20 and \$0.75 per acre inch of water applied. Considering cost of water control, crop responses, and crop values, it is certain that the control of soil moisture is feasible for a wide range of locations and crops in Florida.

SUMMARY

If one considers that all man-made influences on the presence or absence of water over the soil surface and the level of moisture in the soil, are forms of water control, then, the conclusion that water control is a significant limiting factor in field crop production in Florida is certain. Proper balance of moisture in the root zone and aeration in the root zone of plants are necessary for healthy, vigorous growth. Research results indicate a favorable production response to irrigation, drainage, and "water-control." Workable systems for water control have been developed and tested for practically every crop, soil type, and topography of Florida. The backlog of information on cost of water control practices, flood and drought probability, and crop response is adequate for determining the feasibility of developing a water control system for field crops in Florida.

LITERATURE CITED

1. Gallatin, M. H. Irrigation, Moisture, Water Table Studies and Nitrate Leaching. Florida Agr. Exp. Sta., Annual Report. p. 319. 1955.
2. Harrison, D. S. Water Table Fluctuations in Organic Soils of South Florida During Periods of Drainage and Irrigation. Soil and Crop Sci. Soc. Fla. Proc. 19: pp. 352-356. 1959.

3. Hodges, E. M., D. W. Jones and F. M. Peacock. Pasture Irrigation. Florida Agr. Exp. Sta., Annual Report. p. 336. 1957.
4. Hunziker, R. R. Water Relations with Citrus in the Coastal Area. Florida Agr. Exp. Sta., Annual Report. p. 209. 1959.
5. Jamison, F. S. Irrigation of Vegetables in Florida. Soil and Crop Sci. Soc. Fla. Proc. 15: pp. 173-175. 1955.
6. Lutrick, M. C. and C. E. Hutton. Irrigation Studies on Field and Pasture Crops. Corn Fertility. Florida Agr. Exp. Sta., Annual Report. p. 326. 1956.
7. McCloud, D. E. Water Requirements of Field Crops in Florida as Influenced by Climate. Soil and Crop Sci. Soc. Fla. Proc. 15: pp. 165-172. 1955.
8. McCloud, D. E., I. M. Wofford, and E. S. Horner. Irrigation of Field Crops. Florida Agr. Exp. Sta., Annual Report. p. 53. 1956.
9. Marshall, S. P. and J. M. Myers. Irrigation of White-Clover Pangolagrass Pastures for Dairy Cows. Florida Agr. Exp. Sta. Bul. 607. 1959.
10. Myers, J. M. and Fred Clark. Irrigate Tobacco on Schedule. Florida Agr. Exp. Sta. Cir. S-104. 1958.
11. Richards, L. A. and E. J. Richards. Soil Moisture. 1957 Yearbook of Agriculture. U. S. Government Printing Office, Washington, D. C. pp. 49. 1957.
12. Stevens, J. C., W. H. Speir and F. T. Floyd. Design and Maintenance of Water Control Facilities for Florida. Florida Agr. Exp. Sta., Annual Report. p. 249. 1956.
13. Taylor, S. A. Use of Moisture by Plants. In the 1957 Yearbook of Agriculture. U.S. Government Printing Office, Washington, D. C. pp. 66. 1957.

Relationship of Plant Diseases to Field Crop Production in Florida

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Throughout recorded history the impact of plant diseases on food production has been recognized. Even though it is impossible to determine the destructiveness of diseases in early civilizations, there are indications that it was of great magnitude. The fact that records in the Bible indicate plant diseases (blasting and mildew) were among the severe penalties for wrongdoing indicates that they were widely known and feared. In addition, during the glorious days of ancient Rome, the gods dealing with matters of agriculture made up the supreme council of the deities and one of the most powerful of this group was Robigus, the rust god.

In more recent times, plant diseases have actually changed the course of history. A classic example of this is the great famine in Ireland in the 1840's that was a direct result of the destruction of the potato crop by late blight. During this catastrophe, one-fourth of the population of Ireland either died of starvation or migrated to other countries, principally the United States. This situation brought about not only sweeping land reforms but also the abolition of the Corn Laws which had restricted free trade among nations. Indeed, repercussions of this event are still being felt today, e.g. both the paternal and maternal great-grandfathers of the president-elect of the United States were among those who came to this country from ravaged Ireland.

A disaster such as the Irish famine is not likely to recur under our modern system of agriculture, but it could. As recently as the 1920's, acute grain shortage due to plant diseases occurred in this country. If such a shortage could occur in this country in such recent times, it could

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take place in less progressive countries today. Consider what would be the results of the destruction of the rice crop by blast in countries of the Far East.

Fortunately, in the United States plant diseases are viewed from a monetary standpoint and not one of survival. On this point it is generally agreed that losses due to uncontrolled plant diseases amount to 10% annually in the United States. Such a loss amounts to several billion dollars. Due to the prevailing climatic conditions, losses in Florida are probably above the national average. But based on the 10% figure and the recently released market value of field crops grown in Florida, the growers of these crops suffered a monetary loss of over 5 million dollars in 1959. In addition to this calculated loss, there are intangible ones on which a value cannot be placed. Included in these losses would be those resulting from the necessity of purchasing extra livestock food and fertilizer, and profits that might be realized from certain crops that cannot now be grown in the state due to plant disease alone.

The limitation on field crop production caused by diseases can be divided into two broad categories: One, cases where diseases actually curtail growing of a particular crop in an area; and two, cases where they reduce, in one way or the other, the yield of crops that are grown. Fortunately, the latter condition is the most common. However, there are cases where the former is true and no doubt without the modern methods used in agriculture there would be many more. For example, it is possible that tobacco would not be the important crop in Florida that it is if successful controls for blue mold and black shank had not been found. Controls were found and they represent the two most widely used methods of disease control, through the use of fungicides in the case of blue mold and of resistant varieties in the case of black shank.

At the present time there are at least three crops that cannot profitably be grown in this state due to diseases. There are no doubt others but these three appear to have a definite place in Florida agriculture. They are lupine, barley and rice. Lupine was at one time grown extensively in Florida. It was an ideal crop in that it not only provided forage during the winter but was an excellent legume cover crop. It was successfully grown for approximately 12 years. However, as it became more widely planted, diseases and insect pests became more numerous and destructive. These diseases, especially yellow bean mosaic (YBM) finally forced many growers to abandon the growing of lupines. Unless effective control measures are found, this crop may pass completely out of the Florida agricultural picture. Many consider that it already has. Barley might well be a profitable crop to grow in Florida due to the rapid increase of the brewing industry in the state. However, spot blotch and net blotch both caused by species of *Helminthosporium* prevent the growing of this crop. Rice has long been one of the staple food crops of the world that at one time was grown in Florida. Within the past 3 years, a serious virus disease known as hoja blanca was found in rice plantings in the state. This was the first occurrence of this disorder in the United States and in order to prevent its spread to other areas, rice production in Florida was halted.

The three previously mentioned crops represent extreme cases; however, there are others in which disease may be considered as one of the factors preventing larger scale production. The lack of an adapted variety of wheat that is resistant to mildew and rust limit the acreage of this important grain. Grain sorghums would probably be grown more exten-

sively if it were not for the various head molds and leafspots that affect them in Florida. The future of these two potentially important crops in the state depends to a large extent upon the reduction of disease losses.

Thus far, limitations of diseases on field crop production falling into the first broad category have been covered. The second category, consisting of the effect of diseases on the yield of extensively grown crops, is broader and more difficult to evaluate.

The acreage planted to soybeans and forage legumes has increased during the past few years. These crops are beset with many major diseases that have the potential for limiting their production. This potential will become greater as the use of these crops becomes more widespread. Only time will tell which of the major disease are the most important on a given species within this group. However, at the present, on soybeans the diseases bacterial pustule and blight appear to be the most important while clovers are affected most severely by root and crown rots caused by *Rhizoctonia* and *Sclerotinia*. There are indications that the production of alfalfa in the state is being limited by diseases, primarily crown rot, target spot and other leafspots.

The successful growing of small grains such as oats and rye in the state is contingent upon the control of diseases through resistant varieties. Due to appearance of new races of crown rust the average life of an oat variety is about 5 years. Therefore, plant breeders must continually search for new disease resistant varieties and because of this the quest for other desirable characteristics may have to be secondary. Such a condition is clearly a limiting factor due to a disease. In addition to rust, there are other important diseases on oats. *Helminthosporium avenea* reduces the yield by 10-15% each year. Victoria blight caused by *H. victoriae* limits the production of Victoria oat varieties. These varieties have many desirable features including a unique type of resistance to certain destructive races of crown rust. Rye is also affected by rust and various *Helminthosporium* diseases. Today, the rust tolerant Gator rye is being severely affected by an apparently new disease that causes a reduction in seed germination. This disease will have to be controlled if this improved variety of rye continues to be grown.

Field corn has a variety of diseases that attack it. However, the leafspots caused by *Helminthsporium* are the most important. They would limit production of corn in the state if it were not for the existence of tolerant varieties. In the case of corn, as with oats, the breeders spend considerable time in search for disease resistance.

Under certain conditions, peanuts are severely damaged by various diseases. The two most prominent ones are cercospora leafspot and southern blight. Losses due to these two disorders may account for several million dollars each year if they are not controlled to some degree. Fortunately, this can be done, but at an added expense. This added expense could be considered another limitation that disease places on production.

A more extreme case of increased cost due to disease control can be found in tobacco production. In this case, diseases are controlled effectively and economically both in the seedbed and the field. However, the methods of control used would not be feasible on a crop with lower value per acre.

Diseases probably affect forage grasses more than is realized. Certainly very destructive diseases caused by *Rhizoctonia*, *Sclerotinia* and *Helminthosporium* occur on these plants. But it is impossible to place a dollar value

on the damage they do. The losses would have to be evaluated in terms of either cost of additional livestock food or decreased animal carrying capacity of a pasture.

Sugarcane is grown rather extensively in some parts of the state and due to certain factors, the acreage planted to this crop may be increased in the future. The virus diseases (e.g. mosaic and ratoon stunt) and the various stalk rots, especially red rot, are the most serious diseases affecting sugarcane. Any variety that is grown successfully must be resistant to these diseases.

SUMMARY

In summation, plant diseases limit the production of field crops in a variety of ways: 1. They may prevent profitable cultivation of a particular crop. 2. They may materially reduce yield. 3. They may knock out well adapted varieties. 4. They may place a handicap on breeding for other desirable characteristics. 5. They may increase the expense of production. 6. They may force the purchase of additional cattle feed and fertilized.

It is evident that diseases must be effectively controlled in order to obtain maximum production. Thus far, the best method has been through the use of resistant varieties and the search for these must be continued. Except in a few cases, it is not economically feasible to control field crop disease through the use of fungicides, even though effective ones are available. Thus, the search for effective but less costly fungicides, preferably a systemic, must be continued. Basic research concerning the biochemical factors affecting disease resistance may offer a clue to the nature of such a material. This type of research also may provide methods by which the selection for disease resistance may be speeded up. In short, research, both basic and applied, is the key to the effective control of diseases of agronomic crops.

GENERAL REFERENCES
(Not cited)

1. Decker, P. A Review of the Research on the Diseases of Agronomic Crops and their Control in Florida 1939-1959. Soil and Crop Sci. Soc. Fla. Proc. 19:330-338. 1959.
2. Dickson, J. G. Diseases of Field Crops. 2nd ed. McGraw Hill Book Co., New York, New York, 517 pp. 1956.
3. Holton et al. ed. Plant Pathology Problems and Progress 1908-1958. Univ. Wisc. Press. Madison, Wis. 588 pp. 1959.
4. Stakman, E. C. and J. G. Harrar. Principles of Plant Pathology. Ronald Press, New York. 581 pp. 1957.
5. Yearbook of Agriculture. Plant Diseases. U. S. Dept. of Agriculture. Gov. Printing Office, Washington, D. C. 940 pp. 1953.

Insect Pests as a Limiting Factor in Field Crop Production[1]

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One can say without fear of contradiction that every crop grown in Florida is susceptible to attack by insect pests. Sometimes the damage is negligible and so slight that it can be detected only by a careful examination of the plants. In other instances injury is much more severe and in extreme cases insects may cause complete crop destruction. This is by no means a new situation. The author of a Florida Experiment Station bulletin published 70 years ago reported that the average loss of crops in Florida caused by insects was at least 20% and he stated that staple crops sometimes were totally destroyed. The picture remains much the same today and it is estimated that our field crops still suffer losses of 20 to 25% from insect depredations. That seems rather strange in view of present day effective insecticides and improved equipment for applying them. However we must remember that only a small portion of our field crop acreage receives any insecticide treatments and most of this does not get a complete pest control program.

Some variables and complicating factors are involved which make it extremely difficult to evaluate insect losses or to determine to what extent insect pests limit field crop production. The damage to a crop from a certain insect differs from year to year and it also varies from one area to another. Some pests such as the corn earworm and the fall armyworm can be expected in destructive numbers in some part of the state every year. Others like the lesser cornstalk borer may appear sporadically and cause considerable damage for a few years and then fade from the picture for a while. There may also be considerable seasonal variation in the prevalence and destructiveness of certain pests. The corn earworm is a good example of this. In most years, the early plantings of corn in an area suffer little injury from the earworm while fields planted a few weeks later may be severely damaged. Many different factors are involved in this ever changing pest situation and weather probably has a greater influence than any other factor. This is so because weather affects both the pests and the crops on which they feed. Conditions which are ideal for a certain pest may be very unfavorable for the crop that it attacks; and, in other cases the reverse may be true. Because of this seesaw effect it is possible for a given number of insects to cause much more severe damage at some times than at others.

Insect pests cause losses in numerous ways. Perhaps the most important and generally most obvious is reduction in crop yields. This involves a combination of many factors that operate throughout the crop season. Plants may be attacked at any stage from seeding to harvest and in some cases serious injury and losses occur in the stored produce. Small plants may be killed outright, resulting in thin and uneven stands. Plants that survive the early attacks may later suffer root injuries, loss of foliage, or

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destruction of flowering parts that prevent fruit production and result in diminished yields.

Lesser damage may not greatly reduce the volume of the harvest but it can have an adverse effect on the quality and value of the produce. This is a much more important consideration in fresh fruits and vegetables where quality and grade are so important in determining the price received for a crop. Nevertheless quality cannot be disregarded in the case of field crops. Peanut hay from plants badly defoliated by the velvetbean caterpillar will be less palatable and nutritious than hay from uninjured plants. A similar situation exists in the case of field corn damaged by weevils, moths and related pests.

To these direct losses from insect pests we must add others which are less obvious. The depredations of insects can very materially increase the cost of producing and harvesting a crop. If insect pests reduce the yield of a certain crop by 25% it means that a farmer growing that crop must plant, cultivate and harvest 100 acres to get the same return that would have come from 75 acres if insects had not been present. As it usually is impossible to anticipate or predict how much toll the insects will take, growers sometimes try to play safe by planting a greater acreage than is actually needed. If by chance the insects fail to appear or growing conditions are especially favorable, an unusually large crop may be harvested. That will bring about a different but still undesirable result, particularly if the condition occurs over a wide area. In that case there may be a large crop surplus and prices can fall below the cost of production.

To all of these losses and charges attributable to insects we must add the further outlay for pesticides and cost of equipment used in combating the pests.

Now let us consider some of the more troublesome and destructive pests of field crops in Florida. It was mentioned earlier that pests may attack crops at any stage of growth and it also is true that some of them can be expected to appear at any time of year. For convenience we can divide the growing season of any crop in two rather definite periods or stages. In the first or seedling stage, the seeds germinate in the soil and the young plants become established. During that time they are subject to attack by various soil inhabiting pests. Later, as the crop develops and matures the plants are attacked and injured by a generally different group of pests.

Soil insects which cause the most trouble in Florida include such pests as wireworms, cutworms, mole crickets, lesser cornstalk borer, and white-fringed beetles. Wireworms attack all field crops and pastures to some extent, but in Florida they generally do the greatest damage to flue-cured tobacco and corn. A comparatively small number of wireworms can seriously reduce the stand as a single larva may attack several plants during the course of a few days. Many of the plants are killed outright and some that survive are so stunted that they yield little marketable produce. One reason for wireworms causing so much damage is that their presence usually is unsuspected until plant injury begins to appear. For this reason control measures are seldom used against wireworms in field crops in Florida. One notable exception is flue-cured tobacco. This is a high value crop and wireworm damage is frequent enough to warrant the regular use of control measures. The addition of a suitable insecticide to the fertilizer or transplant water certainly is recommended.

Cutworms generally are most troublesome in tobacco, corn and peanuts, though they may cause some injury to all the farm crops. The most severe

damage from cutworms usually occurs when an earlier crop is turned under or a weedy or grassy area is plowed and the new crop is planted immediately. Under these conditions, the hungry larvae are concentrated on the young plants and the stand may be completely destroyed in just a few days. Lesser damage may come from cutworms hatching from eggs laid on the young plants or on the soil near them. If the infestation is discovered early and control measures are applied promptly, it often is possible to save a crop from cutworms after injury begins to appear in the field.

The lesser cornstalk borer is a widespread pest that attacks practically all field crops grown in Florida. It also is one of the most unpredictable. Some years this insect destroys many young plants of corn, soybeans, peanuts and cowpeas in some areas of the state. The next year it may be practically nonexistent in these areas but can be a major problem elsewhere. Nutgrass is a common host of the lesser cornstalk borer and it is known to breed in other weeds also. These wild hosts no doubt serve as a perennial reservoir for the pest but no one has found an explanation for the great fluctuation in numbers from year to year.

Mole crickets are found in all parts of Florida and they injure most of the crops grown in the state. They are most destructive in seedbeds, vegetable fields, and lawns, though they can become a severe problem in field crops at times. Mole crickets are quite capable of killing pasture grasses, especially the Bermudas. Sometimes they seriously injure stands of sorghum, millet, and small grains by burrowing along the drill rows and uprooting the germinating plants.

Prospects for agriculture looked discouraging in parts of West Florida for several years after the white-fringed beetles were discovered in Okaloosa County in 1937. Fields of cotton, corn, peanuts and other crops devastated by this pest could be seen on every hand. The larvae feed on the roots of plants and in some of the more heavily infested fields large completely bare areas occurred where all vegetation had been killed. The surviving plants showed varying degrees of stunting and their foliage was badly damaged by the adult beetles. Early attempts at control were not very effective and some farmers felt that the situation was nearly hopeless.. Fortunately, it was found that a heavy application of DDT to the soil would prevent the beetles from breeding for periods of several years. Other insecticides have proven equally effective and the white-fringed beetles have thus been changed from a major calamity to just another pest that can be controlled effectively and at reasonable cost.

At least a dozen different insect pests attack the above ground portions of field crops in large enough numbers at times to materially curtail crop production. These include the corn earworm, the fall armyworm, the striped grass looper, grasshoppers, the velvetbean caterpillar, spittlebugs, aphids, hornworms, budworms, stink bugs and the boll weevil. Some of these, such as the corn earworm, grasshoppers, and stink bugs, are general feeders that attack practically all of the crops. Others, like the cotton boll weevil and the tobacco hornworm are restricted to single crops. There is no reason to discuss all of these pests individually but we can talk about the corn earworm for a moment. This pest probably has a wider range of host plants and injures more crops than any other insect of major importance. It feeds as a budworm in the whorls of young corn plants and later attacks the ears. Legumes are frequently injured by this pest. The larvae feed on the foliage of peanuts and they bore into the pods of soybeans, cowpeas and lupines and destroy the seeds. Late in the

crop season the earworm often attacks flue-cured tobacco and does considerable damage to the top leaves. On cotton this pest is called the bollworm. As the name indicates, the larvae bore into the developing bolls and cause complete destruction of the lint and seeds. In addition to the field crops, the earworm also attacks many of the vegetable crops grown in Florida and it is by far the most destructive pest of sweet corn.

The corn earworm is capable of causing considerable direct injury to field corn but it is even more important because of its influence on other insect pests. When the earworm larvae in the ears become fully grown they eat holes through the shuck, leave the ears and go into the soil to pupate. These emergence holes in the shucks allow rain and dew to enter the ears and this may cause molds to develop. But much more significant is the fact that the holes provide perfect gateways for weevils and moths. These secondary insects develop and multiply rapidly in warm weather and by harvest time all of the kernels on the ear may be hollowed out and reduced to mere shells. Weevils and moths very rarely enter ears with tight fitting, uninjured shucks, so their depredations in the field must be charged almost entirely to the earworm which prepares their means of entry. To a lesser extent similar situations can be found with other pests on different crops. This illustrates one of the difficulties encountered when we try to make accurate estimates of the amount of damage actually done by the various pests.

Now let us give some thought to the control of these pests we have talked about. What are the possibilities or prospects of reducing the present estimated crop loss of 25% to 10 or 5% or even less? There now are available insecticides, sprayers, dusters and other application equipment that make possible the fairly effective control of most of the insect pests of farm crops. Someone will ask, why are they not being used more extensively? The answer is simple and easy for it is almost entirely a matter of economics. Unless a farmer believes that spraying or dusting his crop to control insect pests will increase the harvest and market value of the produce enough to more than offset the price of insecticides and costs for equipment and extra labor, he will not practice insect control just because it is possible and someone tells him that it is a good idea.

Field corn, sweet corn and tobacco are good illustrations of this principle of economics. We are aware that most Florida sweet corn growers make one or two insecticide applications to control budworms and that all of them put on from six to ten or more applications during the silking period. They have learned that American housewives will not buy wormy sweet corn and they use whatever measures are needed to insure a worm-free product. On the other hand we also know that field corn is rarely sprayed or dusted and that most of the crop is grown without benefit of any pesticide. Certainly the intensive pest control program used on sweet corn could not be justified on field corn but two or three properly timed applications might prove beneficial and profitable. Flue-cured tobacco yields an average per acre return at least three or four times as great as that from field corn. A 25% insect loss in a tobacco field cannot be tolerated and practically all tobacco growers practice a regular pest control program. Yields of field crops will increase through the use of improved varieties and better cultural practices. This, coupled with a growing demand for food to feed a mushrooming population, may someday make a regular pest control program on field crops imperative. That day may come sooner than we expect and it seems the responsibility of entomologists and other

research workers to help farmers prepare for that eventuality.

There are other ways of combating insect pests besides killing them with insecticides. Some years ago crop rotation was frequently recommended as a means of reducing damage from insects. This practice still is helpful in some situations but it is not emphasized today. Crop rotation probably reduces damage to Florida field crops from soil inhabiting pests but it has little noticeable effect on the pests that attack the plants above ground. The latter infestations usually develop from insects that enter the fields from outside areas and sometimes their place of origin may be miles away.

There can be little question that the condition of plants has some influence on their susceptibility or resistance to insect infestation and the amount of damage that they incur. Fertilization and other cultural practices may some day be used as methods of pest control but we need to learn a great deal more about the life processes of the insects and of their host plants before we can make much practical use of these principles.

The discovery or development of crop plants resistant or immune to insect pests holds considerable promise. It has been known for more than 100 years that there are differences in the response of plant varieties to insect attack. Some degree of resistance has been found in varieties or strains of corn, sorghum and other grains to several insect pests that attack those crops. Some strains of corn are known to be lethal to early stages of the corn earworm and the corn borer and young larvae of these pests feeding on the plants are actually killed. Certain strains of cotton have shown resistance to thrips, leafhoppers, aphids, bollworms and the boll weevil.

The theory of resistance to insect attack can be used in two ways. If the plant variety has a high degree of resistance this may serve as the principal control measure. If resistance is less pronounced it can be used to supplement other methods of control. The study of insect resistance in crop plants presents some problems and it requires special methods of investigation. It is completely dependent on close cooperation between entomologists and plant breeders. From the entomological standpoint, a thorough knowledge of the biology and habits of the insect involved is basic and essential to any resistance studies that may be undertaken.

The use of radiation to sterilize male flies was employed in the successful eradication of the screw-worm from the Southeast. Certain chemicals can be used for this same purpose and consideration is being given to the use of these methods as possible means of eradicating or controlling other insect pests. The use of attractants played a very important role in the eradication program used to rid Florida of the Mediterranean fruit fly. It is quite conceivable that modifications of these new methods will prove useful against some of the pests of field crops.

In conclusion we must admit that damage from insect pests in field crops is a problem with which Florida farmers will always have to contend. This does not mean that the situation is hopeless. On the contrary, there is every reason to believe that a thorough understanding of the requirements of the crop plants, a better knowledge of the life histories and habits of pests, and application of the best available control measures will enable farmers to reduce crop losses to insects very materially.

Current Status and Future Development of Research in Plant Nematology

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The plant nematodes definitely constitute a limiting factor in crop production in Florida. Losses in crop production may approach 100% within some fields or portions of fields, particularly where the soil texture is sand or sandy loam. Normally, however, the losses are much less and diagnosis of nematode injury may be difficult. There is no means, at present, whereby one can accurately estimate crop losses within the state due to the ubiquitous nematodes. There is a lack of pertinent information concerning not only distribution and host ranges of the species but also the degree of plant injury that may be caused by any particular population. Therefore, the author will attempt to discuss some of the research needed to bring about a more complete understanding of the nematodes as plant pests.

Every scientist must constantly consider the current status and future development of his chosen discipline. In view of the recent rapid expansion of nematology, contemporary nematologists must, perhaps more than any biological scientists of any period, give serious consideration to future research with a full knowledge of the current status. The problems this undeveloped science faces today are virtually without precedence in the history of endeavors within the biological sciences. Consider the fact that prior to 1948, no university in the United States offered formal courses in nematology and that there existed in the United States only one small research unit whose staff devoted full time to studying the phylum Nematoda. This unit was then named the Division of Nematology of the United States Department of Agriculture and it was established largely through the efforts of one man—the late Dr. N. A. Cobb. Dr. Cobb's staff and a few workers subsequently trained by them provided the nucleus of trained nematologists who have handled the expansion of the science following the introduction in 1945 of the first modern soil nematicides.

Several scientists in other countries; notably England, the Netherlands, Russia, and Germany; devoted full time to nematology prior to 1945. There, too, a continuing nucleus of trained workers was provided. Thus even though formal training within the discipline was not available, the science has a number of trained personnel but the peak of expansion has not been reached. Since 1948, several universities, foreign and domestic, have provided facilities for training of research workers in nematology.

Although no science can be completely separated into various divisions, three of the more obvious phases will be discussed separately. There is no intent of the author to indicate that taxonomy, parasitism, and control are of more importance but most nematological work has dealt with these subjects.

TAXONOMY

Perhaps it is fortunate that much early nematological work was of a taxonomic nature. The foundation for nematode species concepts and

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classification was laid by early workers who were primarily zoologists. Hundreds of nematode species, many of them plant parasitic, and higher taxa were described by such workers as Dujardin, de Man, Bütschli, Bastian, and Kühn prior to 1900. Cobb added a very large number of nematode taxa and, together with the findings of his contemporary workers, provided enough species descriptions so that most of the genera of plant parasites could be distinguished by 1935. Filipjev's 1934 and 1936 papers in which he regrouped most of the plant nematodes seems worthy of mention here. Thorne (17) in 1949 established the order Tylenchida to contain all presently known plant parasites of the class Phasmidia. Thorne (16) also compiled in 1938 the species, genera, subfamilies, and families of stylet bearing nematodes of the class Aphasmidia into the superfamily Dorylaimoidea. Thus, by 1949, all known plant parasitic nematodes had been placed within two taxa. Many species have been described since 1949 and some additions, expansions, and other modifications have been made.

It is believed at the present time that most genera and thus practically all higher taxa of plant parasitic nematodes have been found and described. Some changes and/or clarifications are needed but for the most part plant nematologists would be well advised to proceed very carefully when considering the establishment of new generic or higher category groupings. At present there exists several examples of controversial genera simply because some nematologists have proceeded with premature publication or else did not ask advice of the more experienced personnel.

Future taxonomic work must involve more than just the finding of undescribed forms and preparation of the description. Nematodes are often quite variable in their morphology when moved from one environ to another and much variation exists within colonies of the same environ. Collections of the genus as a whole should be made and the specimens compared microscopically. If possible physiological comparisons should be made in the greenhouse and laboratory. Most of the genera are, or else soon will be, in need of monographic treatment. Certain genera have already been monographed by Allen (1), (2), Sher and Allen (15), Thorne (18), and others. The procedure of publishing single species descriptions in many journals throughout the world has increased the problems of identification and classification. This should be definitely discouraged. There is also need for more completeness in the preparation of future taxonomic publications.

As a result of taxonomic studies most morphological structures of nematoda have been described. A few workers have conducted morphological and physiological studies to unveil more information on anatomical dedetails and functions of the organs. The plant nematodes, in spite of their relatively small size, have many remarkably varied and highly interesting organs worthy of future attention. Their reproductive systems and systems for chemo-reception of various stimuli appear worthy of considerable investigation and might provide highly interesting zoological information.

Life cycles and other bionomical information, while grossly described for most plant parasites, lack considerable detail. Definite life cycles for many of the most important plant parasites await exploration and it is believed that through clarification of taxonomy and the finding of possible weak points in life cycles control may be expedited. As a prime example, the stubby root nematode many times will not reach root destroying popu-

lation levels in the field until after one of the chemical nematicides have been used to control other species. Then there occurs, after about two months, a population explosion so that increases of 1000 times normal are common. Some unknown ecological or bionomical factor has been upset by the nematicide and nematologists must find the explanation for this most unusual and important phenomenon. Many other examples could be mentioned to illustrate needs for future development of the fundamental zoological phases of plant nematology.

PARASITISM AND PATHOGENICITY

The early zoological workers mentioned above realized that many of the nematodes they described were plant parasites but most detailed studies of host-parasite relationships are of recent origin. Rofferdi described a wheat seedgall disease incited by the wheat seedgall nematode *Anguina tritici* in 1775. Berkeley recorded a root-knot nematode as a plant parasite in 1855 and Kühn described the bulb or stem nematode, *Ditylenchus dipsaci*, as a plant parasite in 1857. Kühn and several co-workers were also well aware of the tremendous pathogenic effects of the sugar beet nematode, *Heterodera schachtii*, as early as 1870. Neal (12) and Atkinson (3) provided much knowledge of the host-parasite relationships of the root-knot nematodes. The root-knot disease was studied in much greater detail by Christie (5) and others prior to 1950. Scribner (13) in 1889 followed by Zimmerman (19) in 1898 and Cobb (9) in 1917 added root-lesion nematodes of the genus *Pratylenchus* to the list of plant pathogens. Cobb (8) in 1893 and in later papers described the effects of the burrowing nematode *Radopholus similis* on several hosts, especially sugar cane and bananas. Meanwhile Cobb, Steiner, Thorne, and others realized that certain forms such as dagger nematodes and spiral nematodes feed as ectaparasites but pathogenicity was not definitely established until 1950 or later. Thus practically all detailed studies of host-parasite relationships prior to 1950 were concerned with the endoparasites.

The field of nematology was greatly expanded when Christie and Perry (7) in 1951 reported a serious plant disease incited by the stubby root nematode, *Trichodorus christiei*. This was soon followed by data indicating that sting nematodes, spiral nematodes, awl nematodes, dagger nematodes, pin nematodes, lance nematodes and many others may also incite severe plant maladies.

At present, about 35 genera are known to contain plant parasitic species. This does not mean that all species within these genera attack higher plants since some are known to feed upon fungi or prey upon other nematodes. Actually parasitic relationships are, for the most part, very incompletely known. In some cases, *Trichodorus* for example, only one or two species of large genera have definitely been shown to be plant parasitic. In other cases, pathogenicity to plants has been established for only one or a few species of the genera. Where parasitism and pathogenicity have been established host ranges are most incompletely known and much detailed information of pathogenesis is lacking.

Techniques have been developed for the purpose of establishing the parasitic and pathogenic role of nematodes. Byars (4) in 1914 was apparently the first to develop a pure colony technique for nematodes in sterile plant roots. Christie and Perry (7) used specimens picked one by one into distilled water for inoculating plants in sterilized soil. Mountain

(11) and others have adapted plant tissue or excised root culture techniques for production of sterile specimens of certain species. Sher (14) and others have produced inoculum by placing a few chemically sterilized specimens around host roots growing in sterilized soil and allowing sufficient time for population increases. Linford (10) developed an observation chamber wherein parasitism could actually be observed through the aid of a microscope. One or more of these techniques may be utilized for successful demonstrations of parasitism and pathogenecity by any known nematode. Failure to establish parasitism in a single experiment is not necessarily indicative of a non-parasitic or non-pathogenic nature. Nematodes are extremely fragile organisms and usually perish with any sudden changes in environment such as removal from field soil to chlorinated water to sterilized soil. The removal water should be taken from a natural spring or stream and if distilled or sterile water is used, the specimens should not remain in it for more than an hour or so. Otherwise they will likely suffer from lack of oxygen. The test soil should be of the same type as that from which the nematodes were collected and test pots must never become dry or be subjected to much temperature fluctuations.

Research concerning parasitism and pathogenicity is needed in order to determine more accurately when and where crop damage occurs. Feeding habits of many species presently listed as probable or suspected plant parasites must be determined. Many stylet bearing genera, of which nothing is known concerning the feeding habits, are found in the rhizosphere of plant roots, frequently in large numbers. As stated previously, host ranges of most species are incompletely known. Whenever and wherever a known plant parasite is found associated with plant root destruction the nematode must at some time be isolated and pathogenicity to the particular host species and variety obtained. Consider for example the lance nematode and turf problems in Florida. This parasite is commonly found in large numbers associated with poor turf and the usual assumption is that the nematode incites the trouble. Actually, however, no pathogenicity tests have been conducted and, while there remains little doubt that lance nematodes are highly pathogenic to the grasses, actual data are lacking. This is only one example of hundreds of cases that nematologists are faced with annually. Future research into the modes of feeding and the inciting of plant diseases must be greatly expanded to place the science on firm ground.

In examples where a high degree of pathogenicity for particular plant nematodes on certain hosts has been well established the mode of injury is incompletely known. It is believed that most of the pathogenic effects are brought about by host reactions to the esophageal secretions, probably enzymatic in nature, and their effects are extremely interesting. Consider for example, the giant cells produced as a result of parasitism by root-knot nematode species. These so called nectarial cells must be considered among the most interesting of all plant malformations and are undoubtedly produced as a result of the nematode esophageal secretions. Yet, the exact chain of events leading to giant cell formation is not known and the nematode secretions have not been identified. Another most interesting host response is represented by the cessation of mitotic activity by root tips after they have been fed upon by the stubby root nematode. This nematode is equipped with a very thin stylet and neither the nematode nor its stylet penetrates more than one or two cell layers. There is no necrosis of individual cells or tissues yet the entire root tip ceases to grow and will

not grow again, but maturation of tissues continues so that mature xylem elements are found near the tips of roots. Once again the chemical nature of these enzymes is unknown. These and many more extremely interesting but as yet unknown compounds are produced by plant nematodes while they feed.

Ecological relationships of plant nematodes have been explored to some extent. Interrelationships between different organisms in bringing about plant diseases is considered an important phase for future research. The soil and its biological organisms are of complex nature and no soil borne disease is simply a relationship between the host and its parasite. There is much competition between soil organisms. Plant nematodes are present in all soils but reach damaging populations only when the environment is more favorable to them than other competitors. Such organisms as fungi, bacteria, insects and saprophagous nematodes may consumate plant damages incited by parasitic nematodes.

CONTROL

Christie (6) and others have discussed the present status of nematode control. The first really useful chemical nematicides were introduced in 1945 and little improvement has been made since except in development of techniques for proper application. These nematicides have had a profound effect in expanding the science. Nematologists now have chemical tools to determine when and where nematode diseases of plants occur and, of perhaps more importance, the effects of the nematodes can be demonstrated in fields to other scientists and the public. These nematicides and later ones are not infallible and their effects may extend far beyond the killing of plant nematodes. During wet and cold weather bacteria may be affected to the extent that the nitrification processes are inhibited. There may be direct phytoxicity to crops, beneficial organisms other than nitrification bacteria destroyed. The chemicals, when properly used, have a short life in soil and most harmful effects disappear within a few days. While far from perfect, they represent the only means of quickly ridding large quantities of soil of harmful nematode populations. There is simply no other recommendation in most cases.

Many control procedures other than chemical means have been developed for specific usage. Certain nematodes, cyst nematodes of the genus *Heterodera* for example, have narrow host ranges and crop rotations are used for successful control. Flooding, drying, or combinations of the two are used in some areas especially for the control of root-knot nematodes. Plant quarantines are employed to prevent the spread of certain nematodes and also to assure purchasers of parasite free planting stock. Hot water and chemical solution dips have been developed to kill nematodes within certain plant tissues.

Plant breeders and nematologists have made progress toward the development of resistant varieties of only a few plants to a few nematodes. In most cases varieties resistant to a wide range of nematode species have not been developed. Thus this type of control has been useful only in cases where the plant is attacked by one or a few species within a local area. Non-host trap crops to attract the nematodes but prevent reproduction have been employed, generally unsuccessfully.

The above and several other types of control are utilized but most are preventive treatments. Preventive treatment is the only logical type control

for most annual crops since by the time visible symptoms occur the crop may already be damaged appreciably. Through clarification of bionomical factors and pathogenicity of species to specific hosts, predictions of damage may be expedited. Work is needed to improve determinations of plant parasitic nematode population potentials within given fields. In some cases this might be accomplished by direct examination but in others a technique of growing indicator plants is indicated. Recognition of the frequent nematode damage to perennial plants has emphasized the need for measures to rid infected plants and the surrounding soil of harmful nematodes. Some of the newer soil nematicides may be used in certain instances but exact procedures for application are yet to be determined. The possibilities of systemic nematicides have been explored to some extent but at present there is little indications of success.

Most nematologists are in no position to search for improved chemical nematicides. Commerce is testing hundreds of compounds annually and it is hoped that more effective yet, less phytotoxic, soil nematicides may be found, perhaps even one that is systemic. Nematologists, however, should direct their attention elsewhere and concentrate on control measures other than chemical. For example, certain plants such as marigold, asparagus, and pangolagrass have been shown toxic to plant nematodes when grown in infested soil. Pangolagrass is at present used in a pasture-vegetable rotation in southern Florida and apparently significantly reduces the incidence of root-knot nematodes on vegetable plants. Perhaps other plants may be found, even one which might be interplanted with perennials, to produce root secretions toxic to soil nematodes. Biological control through the use of natural enemies appears possible in limited area crop production and with future development possible field control is indicated, especially if used to prevent re-establishment of populations following more direct control.

Searches for breeding stocks resistant to nematodes should be broadened but this appears limited to localized areas because of the geographical variations both within and between species of the parasites. Certain cultural control practices may be further developed for local areas also.

In other words, future research in developing control measures for the plant nematodes must not follow only the chemical measures as has been the tendency since 1945. Actually no one measure will prove satisfactory or practical in the future. It is believed that the growers who most successfully combat nematodes in the future will do so by a combination of several of the procedures mentioned above.

LITERATURE CITED

1. Allen, M. W. A Review Of The Nematode Genus Tylenchorhynchus. Univ. Calif. Publ. Zool. 61 (3): 129-166. 1955.
2. Allen, M. W. A Review Of The Nematode Genus Trichodorus With Descriptions Of Ten New Species. Nematologica, II: 32-62. 1957.
3. Atkinson, G. F. A Preliminary Report Upon The Life-history and Metamorphoses Of A Root Gall Nematode, Heterodera radicicola (Greef) Müller, And The Injuries Caused By It Upon The Roots Of Various Plants. Bul. Ala. Polytech. Inst., N. S. No. 9. 1889.
4. Byars, L. P. Preliminary Notes On The Cultivation Of The Plant Parasitic Nematode Heterodera radicicola. Phytopathology 4: 323-326. 1914.
5. Christie, J. R. The Development Of Root-knot Nematode Galls. Phytopath. 26 (1): 1-22. 1936.
6. Christie, J. R. Plant Nematodes, Their Bionomics And Control. Fla. Agri. Exp. Sta., Gainesville. 256 pp. 1959.

7. Christie, J. R. and V. G. Perry A Root Disease Of Plants Caused By A Nematode Of The Genus Trichodorus. Science Vol. 113 (2937): 491-493. 1951.
8. Cobb, N. A. Nematodes, Mostly Australian and Fijian. Linn. Soc. N. S. Wales, Macleay Mem Vol.: 252 & 308. 1893.
9. Cobb, N. A. A New Parasitic Nema Found Infesting Cotton And Potatoes. Jour. Agri. Research 11: 27-33. 1917.
10. Linford, M. B. The Feeding Of Some Hollow-stylet Nematodes. Proc. Helminth. Soc. Wash. D. C.: 41-46. 1937.
11. Mountain, W. B. A Method Of Culturing Plant Parasitic Nematodes Under Sterile Conditions. Proc. Helm. Soc. 22 (1): 49-52. 1955.
12. Neal. J. C. The Root-knot Disease Of The Peach, Orange, And Other Plants In Florida, Due To The Work Of Anguillula. U. S. Dept. Agri., Div. Ent. Bul. 20, 27 pp., 21 pl. 1889.
13. Scribner, F. L. Diseases Of The Irish Potato. Bul. Tenn. Agri. Expt. Sta. s (2): 27-43. 1889.
14. Sher, S. A. A Disease Of Carnations Caused By The Nematode Criconemoides xenoplax. Phytopathology 49 (11): 761-763. 1959.
15. Sher, S. A. and M. W. Allen Revision Of The Genus Pratylenchus (Nematoda: Tylenchidae) Univ. Calif. Publ. Zool. Vol. 57 (6): 441-470. 1953.
16. Thorne, G. A Monograph On The Nematodes Of The Superfamily Dorylaimoidea. Capita Zoolgica 8 (5): 1-190. 1939.
17. Thorne, G. On The Classification Of The Tylenchida, New Order (Nematoda, Phasmidia). Proc. Helminth. Soc. Wash. Vol. 16 (2): 37-73. 1949.
18. Thorne, G. Fifteen New Species Of The Genus Hemicycliphora With An Emended Description of H. typica de Man Tylenchida criconematidae. Proc. Helmin. Soc. Wash., 22 (1): 1-16. 1955.
19. Zimmerman, A. Die Nematoden Der Koffiewortels. Meded. Plantentnin. Batavia 27: 16-41 1898.

Weeds as a Limiting Factor in Crop Production

EARL G. RODGERS AND MERRILL WILCOX[1]

Since the beginning of crop production, man has been confronted with reduced crop yields because of vigorous competition from growth of unwanted plants, or weeds. Production of many crops has been and continues to be largely a battle with weeds.

The many weed species prevalent in any area are well adapted to environmental conditions; indeed, if they were not so well adapted, they would have long since become extinct. Crop plants, on the other hand, lack the vigor and degree of adaptation necessary to grow and flourish in any area without the continued protection of man. A principal part of man's activities in producing a crop, then, is to provide an environment, free of serious competition from weeds, in which crops can flourish and produce good yields.

When a cultivated field is abandoned, regardless of its productive capacity, annual grasses and broadleaved weeds rapidly take over. These soon are replaced by perennial grasses, sedges, and shrubs. This succession of plants continues, if undisturbed by man, until a climax vegetation is predominant beyond which no further natural change in the plant population will occur. This climax vegetation may be a pine-turkey oak complex on the more sandy soils of Florida, or it may be hickory-sweetgum type of complex on some heavier soils. The natural tendency, then, is for weeds to predominate in an area and for plant succession to occur. Crop

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production requires continued effort to prevent the recurrence of this natural succession.

Weeds cost American agriculture at least an estimated four billion dollars annually. In Florida, the annual cost of weeds has been estimated to be at least 125 million dollars. These losses are caused in several ways. Competition by weeds for moisture, nutrients, and light causes marked reductions in quantity and quality of crop yields which have been conservatively estimated to be an average of 10% of the total crop value. In any one crop, however, the extent of this loss is influenced by: (a) composition of the weed population, (b) density of the weed population, and (c) length of time competition with crop plants is allowed to continue.

Weeds also cause increased labor and equipment costs. Roughly 16% of the cost of producing many crops is for tillage and cultivation, and approximately one-half of that is due to the presence of weeds. Herbicides presently used for weed control purposes in cropping areas have an annual value of many millions of dollars. Reductions in quantity and quality of livestock products are caused by weeds. Bitterweed and wild garlic in pastures often cause bad flavor in milk. Poisonous weeds are responsible each year in the United States for the death of animals valued at a minimum of 15 million dollars. Several insects and disease organisms are habored by weeds. Infestation of land by such noxious weeds as nutgrass or Johnsongrass usually causes a reduced value of such land for agricultural purposes.

In addition to such tremendous losses to agriculture caused by weeds, annual non-agricultural costs attributed to weeds amount to an estimated billion dollars per year. Railroads, public utility companies, and highway departments spend considerable sums for weed control on their rights-of-way. Control of aquatic weeds in drainage ditches and lakes has become big business. And many weeds are a menace to public health; large segments of our population are susceptible to hay fever caused by ragweed pollen and skin dermatitis or more serious effects after contact with poison ivy and related species.

Despite such losses, some benefits may be attributed to weeds. Organic matter, containing valuable plant nutrients that otherwise might have been lost by leaching, often is added to the soil by weeds. Some weeds, such as Florida redtop (*Tricholaena repens*), may serve as pasture and hay plants. Serving as a vegetative cover, weeds frequently reduce or prevent soil erosion. These advantages, however valuable in their place, fail to compensate for the huge annual losses in agriculture caused by weeds.

Weed control is an integral part of crop production that must be carried out to meet the food, feed, and fiber demands of today. A combination of mechanical, cultural, and chemical methods of controlling weeds has proven to be more effective in reducing crop production costs than the use of any one method alone. The use of a properly prepared seedbed followed by clean, efficient, shallow, timely cultivation is important. Adapted crop varieties, properly fertilized and managed, and grown in a sound rotation also are important and very basic to success. Pre-emergence and post-emergence applications of herbicides may be used safely in many crops.

Some weed species are strong competitors, difficult to control, and tend to cause serious reductions in crop yields wherever they occur on cultivated lands. A common example is nutgrass (*Cyperus rotundus*). This sedge interferes with normal cultivation, draws heavily on nutrients and moisture

in the soil, seriously reduces yields of cultivated crops, and defies eradication by practical mechanical, cultural, and chemical means so far devised. At best, individual eradication or control efforts have caused only temporary stunting or thinning the population of this weed. Many herbicides have been used in efforts to control nutgrass with varying degrees of success. Soil sterilization with methyl bromide probably is most effective, but the air-tight soil cover required renders this treatment impractical on a field basis. Vapam also has produced good results, but again a temporary soil cover is needed immediately after application. For field use, repeated applications of 2,4-D alone or in mixture with amitrol have caused marked reductions in nutgrass density, even though of a temporary nature. Eptam has shown marked reduction in density of this weed, but has not provided complete eradication. The real problem of control lies not just in killing the tops and roots of plants growing at any one time but also in killing the highly viable tuber that are widely dispersed through the soil to depths of at least 24 inches. No treatment has been devised thus far that will so perform.

Several perennial grasses also compete severely with crop plants on cultivated lands. Common examples are bermudagrass (*Cynodon dactylon*), Johnsongrass (*Sorghum halepense*), and in south Florida, paragrass (*Panicum purpurascens*). These grasses generally cannot be controlled completely by mechanical means, but effective control usually can be provided by applications of dalapon. One application of 20 pounds per acre will greatly reduce the grass population. Repeated applications of five pounds per acre at intervals of 10 days to two weeks for a minimum of three applications provide even better control. Discing the soil midway in the interval between successive applications seems to increase the herbicidal action.

Weed infested fence rows usually render the adjacent strip of soil useless for crop production. Weeds and brush allowed to flourish undisturbed send out roots several feet away from the fence and detract significantly from the crop producing ability of nearby soil. Such weeds and brush may be controlled by herbicides and thereby allow effective crop production nearer fences. A 1:1 ratio of 2,4-D:2,4,5-T (low volatile esters) at a concentration of four pounds acid equivalent per 100 gallons of water sprayed to wet the brush foliage during spring and early summer months will kill a large percentage of the undesirable plants. In recent years, a popular practice has been to apply monuron or diuron at minimal rates of 10 pounds per acre in strips of desired width astride the fence. These materials, so applied, kill practically all plants growing or having roots extending into the treated strip by soil sterilization and therefore provide a weed-free fence row for one to two years before retreatment is necessary. These materials are non-corrosive to the fence and non-toxic to animals, but they will damage and probably kill nearby plants or trees having roots that extend into the treated strip.

In the production of individual crops, many weed species are present. The most prolific and troublesome annual weeds, however, often have a growth habit somewhat similar to that of the crop plant with which they are competing. Some examples will be considered.

The presence of such annual weeds as Florida pusley (*Richardia scabra*), sandbur (*Cenchrus spp.*), and crabgrass (*Digitaria sanguinalis*) in peanut fields causes considerable reduction in yields unless effective control is provided. Since these weeds have a decumbent growth habit similar to that of the peanut plant, they interfere with normal peanut harvesting

operations and often cause some peanuts to be left in or on the ground that otherwise might be saved. Control of these weeds between the rows can be accomplished effectively with conventional cultivation. The hoe has been used effectively to remove the weeds growing in the row; however, the high price and scarcity of farm labor in recent years have caused a decline in use of this method of weed control.

More effective control in recent years has been provided by pre-emergence applications of DNBP on lighter soils and sesone on the heavier soils. Rates of 9 to 12 pounds per acre of the former material and 3 to 5 pounds per acre of the latter applied in 20 to 30 gallons of water per acre to the soil surface after the peanuts are planted but before the seedlings emerge usually provide satisfactory control of most annual weeds for 8 to 10 weeks. The sprayer usually is attached to the tractor and planter so that the soil surface is sprayed immediately behind the planter to perform both planting and spraying in one operation. A more common practice is to spray only a band of soil 12 to 14 inches wide astride the row to control weeds in the drill; the quantity then required would be reduced proportionately to the percentage of the soil surface covered. Normal cultivation then would control the weeds in the middle, and the peanuts will be of sufficient size to shade out emerging weed seedlings in the row when the herbicides break down to allow such emergence. The hoeing of large acreages of peanuts has thereby become almost obsolete.

Weeds that significantly affect corn production usually have erect types of growth. Such weeds as ragweed (*Ambrosia artemisiifolia*), cocklebur (*Xanthium spp.*), and showy crotalaria (*Crotalaria spectabilis*) commonly compete with the corn plants for nutrients and moisture and often seriously interfere with harvesting, particularly when a mechanical harvester is used. Corn grain harvested mechanically from fields heavily infested with showy crotalaria usually is contaminated with crotalaria seed. Such contaminated grain often cannot be sold or is severely docked for milling or feeding purposes since the crotalaria seed are poisonous in nature.

Since the corn plants grow erect and often are planted in a furrow 2 to 4 inches deep, many weed seedlings can be killed in the row during the early growing season by being covered with soil from cultivation beside the row. Erect growing weeds in the drill, however, usually are not affected.

Considerable acreages of corn have been sprayed in recent years with pre-emergence applications of simazine at 2 to 4 pounds per acre. Most annual weeds have been controlled for periods varying from 2 to 5 months by this treatment. Post-emergence applications of one-half pound per acre of an amine formulation of 2,4-D when the corn is 12 to 18 inches high have been in common use in the corn belt. Higher rates of 2,4-D may be required if the weeds are larger, particularly when needed to kill showy crotalaria, but the rate should not be sufficiently high to damage the corn.

In the production of soybeans, some of the more dreaded weeds are similar in growth habit to the soybeans. This crop is highly sensitive to post-emergence applications of herbicides, but pre-emergence applications of PCP and CIPC have shown much promise of controlling many annual weeds without injury to the soybeans.

Small grain production in Florida usually is not seriously affected by weeds because these crops, except rice, grow during the cooler seasons of the year when most weeds are either dormant or least agressive, and also because most of the acreage is used for grazing in the early growing period. The limited acreage of these crops grown for grain, however, may en-

counter competition from such weeds as wild mustard (*Brassica spp.*) or other broadleaved winter annuals. These weeds usually may be controlled by application of 2,4-D sprays.

Various types of weeds are found in pastures and the degree of infestation is greatly influenced by the type of management followed. Good fertilization and regulated grazing stimulate established forage plants into maximum production and usually thereby deny weeds the opportunity of becoming established in great numbers. However, overgrazing and/or under-fertilization reduce the vigor of the forage plants to the point that weeds often become established without difficulty and may eventually crowd the pasture plants into non-productivity. Mechanical mowing is commonly practiced to prevent excessive weed infestations. However, 2,4-D, 2,4,5-T, or related compounds may be used in grass pastures to control most broadleaved weeds; these herbicides often are not safe to use in grass-legume pastures because of the probable injury to the legumes. A relatively new herbicide—4-(2,4-DB)—can be used on most pasture legumes with comparative safety while providing control of most annual weeds. Exact rates of these herbicides would be determined by the particular forage plants in the pasture and the weed species to be controlled.

These and many other weed problems seriously retard normal crop growth and result in reduced yields. Standard tillage and cultivation should be practiced for weed control purposes until a specific herbicidal treatment is developed for safe use with each crop. When such a safe herbicidal treatment is developed, it's use in proper combination with older practices may be desirable to reduce the over-all cost of crop production.

SYMPOSIUM: SOIL TESTING

W. L. Pritchett and J. NeSmith, Presiding

Brief History and Present Status of Soil Testing in Florida

JAMES NESMITH[1]

Soil testing had its beginning something over 100 years ago when Daubeny, in 1845, used carbonated water to extract soil nutrients. Apparently very little was done in soil testing for the next 25 years or so until Liebig started extracting soils with dilute mineral acid solutions to determine their nutrient status. He used soils from the Rothamstead Experiment Station for his study. In the latter part of the 19th century, Dyer published an extensive paper in which he presented soil test and crop response correlations. A one-percent citric-acid solution was used for this work.

In the 25 to 30 years following 1900 much basic soil chemical data was collected in the United States. Total phosphorus, potassium, etc. were determined. Hilgard, in his first text book entitled "Soils," noted that the soils of Mississippi, containing less than about 0.1% total P_2O_5, usually responded to phosphorus applications. Much of the basic soils data collected in the first part of this century is used as background information for present day work.

Soil testing today is not basically different from what it was in the beginning. The philosophy and interpretation of soil testing, however, was changed somewhat over the years. Some early workers attempted to duplicate the action of plant roots in removing plant nutrients from the soil complex while others used the total nutrient content of the soil approach. As a rule, present day soil test methods are selected on a basis of their adaptability to modern instrumentation and calibration and generally only the easily extractable nutrients are determined.

Soil testing was thought by some to be *the* answer to plant nutrition and crop production problems. Today, however, I think most of us realize that soil testing is only one of several effective tools used in tackling these problems. The key to present day soil testing is the proper calibration and interpretation of soil test results and plant response. Soil testing is *not the* answer to the problems mentioned but is just *one* of several vital tools used to help improve agriculture.

In 1901 the report of the Chemist (now Department of Soils) of the Florida Agricultural Experiment Station reported analyzing a number of materials, several of which were soils and similar reports through the years indicated that soils had been analyzed rather routinely.

During the 1930's there was a tremendous increase in soil testing in Florida and the Southeastern states. There were several reasons for this increase in the state at that time but probably the major impetus came from the citrus industry. Nutritional disorders in citrus were the rule rather than the exception. Research workers as well as private individuals and industry turned to soil testing to help clarify the situation. Soil reaction was probably most frequently determined but as experience and

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knowledge increased, laboratories improved their facilities so as to make other nutrient determinations.

Over the years, the number of soil samples received at the Soil Testing Laboratory in Gainesville increased to the extent that it was taking much time from research. As the number of soil samples increased, so did the calibration information but we are still woefully short of sufficient calibrated data for soil testing. I don't know if it is any consolation or not but most every other state is lacking in sufficient calibrated soil test data also.

Soil testing at the University of Florida, handled for many years by the Experiment Station, grew to the point that some adjustment had to be made. So after considerable study and planning, the Soil Testing Laboratory was transferred on July 1, 1959 to the Agricultural Extension Service. In the fiscal year 1959-60 the Laboratory in Gainesville analyzed 19,672 soil samples, 14,836 of which were extension or service type samples and 4,029 were for research and 807 were classified as miscellaneous. The research samples were almost all concerned with calibration work.

In addition to the Soil Testing Laboratory in Gainesville, laboratories located at Experiment Stations in Belle Glade and Quincy handle service soil testing work for their respective areas. The Everglades Experiment Station at Belle Glade is primarily concerned with testing the organic soils of that area while the North Florida Experiment Station in Quincy handles the highly specialized cigar-wrapper tobacco samples. There are two county laboratories in the state, one in Dade and the other in Escambia County. The Dade County laboratory is concerned mainly with marl soils.

There are a number of private and industry laboratories in the state doing soil test work. At the present time, Dr. Herman Breland and I are making a survey of these laboratories. We hope that in the future we can help these various labs with their technical and applied problems. Information as to improvements and changes in the technical phases of soil testing as well as assistance in "quality control" measures should improve soil testing in Florida.

A preliminary or progress report of the survey just mentioned is to be found in the pages that follow.

REFERENCES

1. Symposium on Soil Testing—Journal of Agricultural and Food Chemistry, March and April, pp. 84-101. 1960.
2. Symposium: Soil and Tissue Testing—Soil Sci. Soc. Fla. Proc. Vol. XIII, 89-159. 1953.

Soil Analysis in Florida — A Progress Report[1]

HERMAN L. BRELAND and JAMES NESMITH[2]

Soil analysis has been viewed in many ways by different people—from a psychological tool to a soil management cure-all. Unfortunately it will not solve all the problems of crop production. However, when properly used, it may help, just as cultivation, fertilization or insect control helps to reduce the odds against making a good crop. There is ample evidence to substantiate the benefits that may be obtained from soil analysis when the data have been properly interpreted and the recommendations followed. This has resulted in a tremendous increase in the demand for soil analysis. A number of new laboratories have been established in the state because of this demand. If the trend continues, the demand for soil analysis will undoubtedly increase many fold in the next few years.

In spite of the interest in soil analysis and the number of laboratories operating in the state there was no complete listing of the facilities available for such work. This is due no doubt to the fact that licenses are not necessary for soil analysis laboratories, therefore, recording or listing was unnecessary. However, the names and addresses of 34 laboratories in the state were obtained and are given in Appendix Table 1. The name of one or more individuals to be contacted for information about the facilities is also given in most cases.

In order to obtain first-hand information about the different laboratories in the state the authors visited 27 of the 34 laboratories during the past six months. Previous surveys regarding soil analysis were made in the state in 1953 (2) and in 1955 (3).

Although the physical facilities of the different laboratories were found to vary considerably, no attempt was made to classify or rate them in any way. Some of the facilities and equipment were excellent and all of the personnel appeared to be conscientious and trying to do a good job. In order to avoid any controversy, the names and addresses of only the county and state laboratories will be given in the following tables. The information about the other laboratories will be listed by number only and not in the same sequence as given in Appendix Table 1.

Three of the laboratories listed under the heading of County, State or Federal Laboratories are not actively engaged in soil analysis as a service, but handle a few samples in addition to their research samples on a trouble-shooting basis. The laboratories referred to are the Citrus Experiment Station, Central Florida Experiment Station and the U. S. D. A. Horticulture Field Station Laboratory.

All State supported laboratories must of necessity devote a considerable portion of their personnel and facilities to research as well as furnish a service to the growers. Most of the research being conducted by the Department of Soils, at Gainesville, as well as that of some other departments, is based either directly or indirectly on soil analysis.

All commercial laboratories listed will make soil analyses. However, two of the laboratories in the citrus area normally process samples only

[1]Florida Agricultural Experiment Station Journal Series, No. 1221.

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during the summer, or slack period. It should also be noted that all, except four, of the commercial laboratories are located south of Leesburg. This is probably due to the high cash value of the crops and the intensive type of agriculture practiced in that area. The commercial laboratory at Quincy handles only samples for a special organization of growers. The other three commercial laboratories are in Jacksonville and handle a total of about 2000 samples per year.

Cost—The County or State laboratories do not charge for the soil analysis service. Many of the commercial laboratories are being operated for the benefit of a particular organization or its customers and therefore no charge is made. In fact, it was found that only 11 of the 23 commercial laboratories in the State charge for the service (Table 1). Laboratories that have no such relationship must charge. The charge per sample varies with the number and kind of determinations requested and whether a consulting service is supplied.

TABLE 1.—THE NUMBER OF SOIL SAMPLES HANDLED, CONTROL OVER THE COLLECTION OF SAMPLES AND THE METHOD USED FOR MAKING THE pH DETERMINATIONS BY EACH LABORATORY.

				Soil pH*	
Laboratory	Charge	Number of Samples per year	Control of samples	Soil:Water Ratio	Soaking Time (hr.)
1. Main Station U. of F.	No	19,000	No	1:2	1
2. Everglades E. S.	No	6,000	No	1:2	2
3. North Fla. E. S.	No	1,500	No	1:2½	1
4. Citrus E. S.	No	100	Yes	1:2	½
5. Central Fla. E. S.	No	2,000	No	1:2	½
6. Escambia Co. S. L.	No	1,200	Yes	1:2	1
7. Dade Co. S. L.	No	2,250	No	1:2	1-2
8.	Yes	1,000	No	1:2	1
9.	No	35,000	No	1:2	1
10.	Yes	5,000	Yes	1:1	1
11.	Yes	400	No	1:1	1/3
12.	Yes	......	No[1]	1:1	1
13.	No	200	Yes	1:1	½
14.	Yes	500	No	1:2½	2
15.	Yes	5,000	Yes[1]	1:2	1-8
16.	No	100	Yes	1:2	1
17.	No	7,000	No	1:1	¼
18.	Yes	30	No	1:1	¼
19.	No	700	Yes	1:1	1/6
20.	No	200	No	1:2	¼
21.	Yes	50	No	1:4	1/12
22.	Yes	100	No[1]	1:2	1/12
23.	No	2,000	No	1:2	2
24.	No	1,500	Yes	1:1½	....
25.	No	100	Yes	1:1	1
26.	No	400	Yes	1:1	½
27.	Yes	1,200	Yes	1:1	½
28.	Yes	.....	No[1]	1:1	1
29.	No	4,000	Yes	1:1	½-1
30.	No	1,500	Yes	1:1	½
		98,030			

*Potentiometer and glass electrodes used for making pH determinations in all cases.
[1]Determinations made on moist soil, all other samples were air-dried and sieved.

TABLE 2.—THE SIZE OF SAMPLE, SOIL: SOLUTION RATIO, EXTRACTANT AND TIME OF EXTRACTION USED BY THE DIFFERENT LABORATORIES.

Laboratory	Sample Wt. (gm.)	Soil: Extractant Ratio	Extractant	Shaking Time (min.)
1 Main Station U. of F.	5	1:5	NH_4OAc pH 4.8	30
2. Everglades E. S.	----[1]	(1:2½ B	CH_3COOOH .5N	
	--[1]	(1:12½ P	Distilled H_2O	
3. North Fla. E. S.	5[1]	1:5	NH_4OAc pH 4.8	30
4. Citrus E. S.	5	(1:5 B	NH_4OAc pH 4.8	----
		(1:10 P	Bray[2]	----
5. Central Fla. E. S.	5	1:5	NH_4OAc pH 4.8	30
6. Escambia Co. S. L.	5	1:5	NH_4OAc pH 4.8	30
7. Dade Co. S. L.	10	1:5	Distilled H_2O	30
8.	10	1:5	NH_4OAc pH 4.8	15
		1:10 P	N. Carolina[3]	15
9.	5[1]	1:5	NH_4OAc pH 4.8	30
10.	8	1:6	NH_4OAc pH 4.8	30
11.	10	1:5	NH_4OAc pH 4.8	
		1:10	Bray[2]	30
12.	10	1:5	NaOAc pH 4.8	30
13.	10	1:10	NH_4OAc pH 4.8	Stand Overnight
14.	40[1]	1:2½	NaOAc pH 4.8	10
15.	10[1]	1:2	NaOAc pH 4.8	1
16.	5	1:5	NH_4OAc pH 4.8	30
17.	10[1]	(1:5 B	NaOAc pH 4.8	30 for Bases
		(1:12½ P	Distilled H_2O	Stand overnight
18.	50	1:1	NH_4OAc pH 4.8	Leached
19.	10	1:5	NaOAc pH 4.8	20
20.	10	1:5	NaOAc pH 4.8	30
21.	100	1:5	Distilled H_2O	15
22.	-- .	.	NaOAc pH 4.8	30
23.	3[1]	1:6	CH_3COOH 0.025 N	1
24.	20	1:2½	CH_3COOH 0.025 N	1
25.	20	1:5	NH_4OAc pH 7.0	30
26.	5	(1:5 B	NH_4OAc pH 4.8	
		(1:10 P	HCl + NH_4F	30
27.	10	1:5	NH_4OAc pH 7.0	30
	.[1]	1:5	Bray[2]	
28.	----	1:1	NH_4OAc pH 7.0	60
29.	10	1:5	NH_4OAc pH 4.8	30
30.	10	1:5	NaOAc pH 4.8	30

[1] Measured
[2] 0.025 N HCl and 0.03 N NH_4F
[3] 0.025 N HCl and 0.025 N H_2SO_4

Soil Samples—The number of samples handled annually by various laboratories varied from less than 100 to over 35,000 (Table 1). The total number of samples analyzed in the state annually by the 28 laboratories was about 98,000. Eleven laboratories handled 500 samples or less; two, 600 to 100 samples; eleven, 1100 to 5000 samples; and three handled over 5000 samples. Approximately 68,000 soil samples were analyzed by the 23 commercial laboratories annually. However, about fifty percent of these samples were handled by one laboratory. The salesmen or representatives are responsible for obtaining or supervising the collection of soil samples for many of the commercial laboratories. In this way it is possible for them to have some control over the number of soil samples received and also how they were taken.

A pH meter (potentiometer) with glass electrode was used for the pH determination by all laboratories visited. All laboratories except two used two buffer solutions for standardizing the instrument. The remaining two laboratories used only one buffer solution.

The soil:water ratio used for the pH determination varied from 1:1 to 1:2½ in all but one laboratory. Approximately the same number of laboratories used each ratio. One laboratory used a soil:water ratio of 1:4. The soaking time allowed after the water was added to the soil samples before making the pH determination varied from five minutes to as much as 8 hours. The majority used a soaking time of less than one hour.

Soil: Extractant Ratio—The size of soil samples used, the soil:extractant ratio and the shaking time used by the different laboratories are given in Table 2. The samples were weighed by the majority of the laboratories, with only seven measuring the samples. A soil:extractant ratio of approximately 1 to 5 was used for the bases (Ca, Mg and K) in 22 of the 29 laboratories reported. In only two instances was a soil:extractant ratio as narrow as 1 to 1 used and two laboratories used a ratio as wide as 1 to 12½ for phosphorus.

Extractant Used—A total of 13 laboratories used ammonium acetate, pH 4.8, as the extractant for removing the nutrients from the soil (Table 2). Laboratories using other extractants totaled 8, 3, 3 and 2 for sodium acetate, pH 4.8; ammonium acetate, pH 7.0; acetic acid and distilled water; respectively. A different extractant was used for phosphorus by 7 of the laboratories. It was either 0.025 normal hydrochloric acid and 0.03 normal ammonium fluoride, 0.05 normal hydrochloric and 0.025 normal sulfuric acid or distilled water. A soil:extractant ratio of approximately 1 to 10 was usually used for phosphorus.

The time of shaking or contact with the soil varied from one minute to standing over night. The methods of extraction used by 27 of the 30 laboratories and the number using each method were: pouring the extractant over the soil in a filtering funnel—1, shaking by hand—8, rotary shakers—4 and reciprocating shakers—14. At least one or two laboratories allow the sample to stand over night after adding the extractant before filtering.

Major Nutrient Determinations—The determinations other than pH generally made on the soil samples were calcium, magnesium, potassium and phosphorus (Table 3). In general, the colorimetric procedures used for the calcium, magnesium and potassium determinations were those of Peech and English (1) or modifications thereof. When the flame photometer was employed the leachates were used without dilution. Phosphorus was determined colorimetrically by using acid ammonium molybdate with either stannous chloride or amino-napthal-sulfonic acid as reducing agents. Only three laboratories were found to be using commercial soil test kits for making determinations.

The number of laboratories making visual comparisons instead of using photo-electric colorimeters for the different determinations were as follows: Calcium—3, magnesium—6, potassium—4 and phosphorus—4. A flame photometer was used in many instances for the first three determinations when the volume of samples was sufficient to justify the cost. This was particularly true for the calcium and potassium determinations. Magnesium, being more difficult to determine by flame photometry, requires an instrument with more sensitivity which was not as widely used due to the increased cost. All laboratories not using the above methods for the calcium, magnesium

TABLE 3.—THE METHODS USED FOR MEASURING THE AMOUNTS OF CALCIUM, MAGNESIUM, POTASSIUM AND PHOSPHORUS REMOVED BY THE EXTRACTANT.

Laboratory	Ca	Mg	K	P
1. Main Station U. of F.	Flame	Flame	Flame	Colorimeter*
2. Everglades E. S.	Flame	Flame	Flame	Colorimeter
3. North Fla. E. S.	Flame	Flame	Flame	Colorimeter
4. Citrus E. S.	Flame	Colorimeter*	Flame	Colorimeter
5. Central Fla. E. S.	----	----	Colorimeter*	Colorimeter
6. Escambia Co. S. L.	Flame	----------	Flame	Colorimeter
7. Dade Co. S. L.			Flame	Colorimeter
8.	Flame	Colorimeter	Flame	Colorimeter
9.	Flame	Colorimeter	----------	----------
10.	Flame	Colorimeter	Flame	Colorimeter
11.	Colorimeter*	Colorimeter	Flame	Colorimeter
12.	Visual	Visual	Visual	Visual
13.	Flame	Colorimeter	Flame	
14.	Colorimeter	Colorimeter	Colorimeter	Colorimeter
15.	Colorimeter	Colorimeter	Colorimeter	Colorimeter
16.	Flame	Flame	Flame	Colorimeter
17.	Colorimeter	Colorimeter	Colorimeter	Colorimeter
18.	Colorimeter	----------	----------	Colorimeter
19.	Colorimeter	Colorimeter	----------	----------
20.	Colorimeter	Colorimeter		
21.	Flame	----------	Flame	Colorimeter
22.	Visual	Visual	Visual	Visual
23.	Visual	Visual	Visual	Visual
24.	Colorimeter	Visual	Visual	Visual
25.	Flame	Visual		
26.	Flame	Flame	Flame	Colorimeter
27.	Flame	Flame	Flame	Colorimeter
28.	Flame and Colorimeter	Visual	Flame and Colorimeter	Colorimeter
29.	Flame	Colorimeter	Flame	Colorimeter
30.	Colorimeter	Colorimeter	Colorimeter	Colorimeter

*Photoelectric Colorimeter

and potassium determinations utilized a photoelectric colorimeter for making the determinations. The concentration of phosphorus in extracts was determined by means of a photoelectric colorimeter in all cases except the four laboratories using the visual procedure.

Minor Nutrients—Several of the laboratories routinely make one or more minor element determinations only upon request. The determinations usually made on request are copper, manganese, zinc, boron and iron. Some laboratories determine the total amount in the sample while others determine only the easily extractable portion. The value of certain of these determinations is questionable unless extensive correlation data are available for the particular method and crop involved.

Other Determinations—The other determinations most commonly made or requested are total soluble salts, total phosphorus, cation exchange capacity, organic matter and total nitrogen. Only one or two laboratories make any of the above determinations except upon request. It is well known that information obtained by any method may be of limited value without specific correlation data or extensive experience in the area.

LITERATURE CITED

1. Peech, M. and L. English Rapid microchemical soil tests. Soil Science 57:167-195. 1944.
2. Smith, F. B. Current Facilities for Soil Testing in Florida on a Service Basis. Soil Sci. Soc. Fla. Proc. Vol. XIII:115-123. 1953.
3. Soil Chemists Meeting, Citrus Experiment Station, Lake Alfred, Florida, November 17, 1955 (Mimeo).

Appendix Table 1

SOIL TESTING LABORATORIES

County, State or Federal Laboratories:	*Contact:*
1. Soil Testing Laboratory Agricultural Extension Service Gainesville, Florida	Dr. James NeSmith Dr. Herman L. Breland
2. Everglades Experiment Station Belle Glade, Florida	Dr. W. T. Forsee
3. North Florida Experiment Station Quincy, Florida	Mr. W. D. Woodward Mr. W. H. Chapman
4. Citrus Experiment Station Lake Alfred, Florida	Dr. William F. Spencer Dr. Ivan Stewart
5. Central Florida Experiment Station Sanford, Florida	Dr. R. B. Forbes Dr. P. J. Westgate
6. Escambia County Soils Laboratory Room 308, County Court House Pensacola, Florida	Mr. James H. Walker
7. Dade County Soils Laboratory 1102 N. Krome Avenue Homestead, Florida	Mr. William R. Llewellyn
8. United States Department of Agriculture Horticulture Field Station 2120 Camden Road Orlando, Florida	Dr. Paul Smith

Commercial Laboratories in State:

1. Agricultural Chemical Laboratories 1710 West Fairbanks Avenue Winter Park, Florida	Mr. B. J. Conner
2. Armour Agricultural Chemical Company E. 8th Street and Talleyrand Avenue P. O. Box 3007 Jacksonville, Florida	Mr. Vernon Moore
3. Citrus Culture Corporation Mt. Dora, Florida	Mr. Richard D. Conkling
4. Dolomite Products, Inc. Pembroke, Florida	Mr. F. S. Battle
5. Florida Chemists & Engineers, Inc. 645 Rugby Avenue Orlando, Florida	Mr. Robert A. Nanz
6. Florida Soil Testing Laboratory 2929 Adams Street Hollywood, Florida	Dr. Harry Bylan
7. Flowers Analytical Laboratories P. O. Box 587 Altamonte Springs, Florida	Dr. J. L. Flowers
8. Haines-Fizette Laboratories US 19 and Ulmerton Road Largo, Florida	Dr. W. E. Haines
9. Hi-Acre Fertilizer Company Groveland, Florida	
10. Holly Hill Fruit Products Davenport, Florida	Mr. Dean Hayes
11. International Minerals and Chemical Corp. P. O. Box 2537 Mulberry, Florida	Dr. Rupert W. Prevatt
12. Libby-McNeil & Libby Clermont, Florida	Mr. William West
13. Dr. Ralph Miller 701 S. Hyer Orlando, Florida	Dr. Roy Bair 256 Alhambra Place West Palm Beach, Florida
14. Minute Maid Plymouth, Florida	Dr. A. L. Wilson
15. H. W. Myers and Associates P. O. Box 681 Sebring, Florida	Mr. C. Lamar Carlton
16. Pasco Packing Company P. O. Box 97 Dade City, Florida	Mr. Morton Howell
17. Plymouth Citrus Growers Plymouth, Florida	Mr. E. L. Mathews Mr. Ed Farley
18. Rowland Laboratories 345 E. Forsyth Street Jacksonville 2, Florida	
19. Soil Science Foundation 1305 East Main Street Lakeland, Florida	Dr. O. C. Bryan Dr. C. N. Nolan

20.	South Lake Apopka Citrus Growers Co-op. Winter Garden, Florida	Mr. George Beck
21.	Southern Analytical Lab., Inc. 128 Talleyrand Avenue Jacksonville 2, Florida	
22.	John H. Swisher & Son, Inc. Quincy, Florida	Dr. Morgan Stickney Mr. Robert Gardner
23.	Thornton and Company 1145 East Cass Street Tampa, Florida	Mr. C. C. Thornton
24.	Waverly Growers Corporation Waverly, Florida	Mr. C. D. Kime, Jr.
25.	Wilson and Toomer Fertilizer Company Drawer 7 Davenport, Florida	Mr. V. E. Woods
26.	Dr. Wolf's Agricultural Laboratories 2620 Taylor Street Hollywood, Florida	Dr. Benjamin Wolf

Commercial Laboratories out of State:

1.	American Agricultural Chemical Company 100 Church Street New York 17, New York	Mr. W. A. Lyerly P. O. Box 37 Pierce, Florida
2.	Brookside Research Laboratories, Inc. New Knoxville, Ohio	

Research and Application of Soil Testing for Organic Soils[1]

CHARLES C. HORTENSTINE and W. T. FORSEE, JR.[2]

INTRODUCTION

Since Liebig proposed his "law of the minimum" over one hundred years ago, soil scientists have attempted to develop methods by which the nutritional needs of a plant may be ascertained and those nutrients found in short supply be added to the soil. During the 1930s, soil testing by state supported laboratories began in a few states in order to meet the growing need for the maintenance of soil fertility.

In July, 1950, the National Soil and Fertilizer Research Committee appointed the Soil Test Work Group (4) with instructions "to consider the whole field of soil testing, its problems and its uses, and to submit recommendations concerning needed activities and improvements." This committee, in answer to inquiries sent to 47 states (excluding Alabama which had no soil testing laboratory at that time), Alaska, and Hawaii found that a total of 1,235,000 soil samples were analyzed by state supported laboratories during 1950.

[1]Florida Agricultural Experiment Station Journal Series, No. 1192.

[2]Assistant Soils Chemist and Chemist in Charge, respectively, University of Florida Everglades Experiment Station, Belle Glade, Florida.

The primary goal toward which soil tests are directed is to determine the supply of a given nutrient in terms of its availability to the plants growing within a particular soil. In 1948, Bray (2) stated: "The requirements for a successful soil test, therefore, may be briefly stated as follows:

1. The extracting solution and the procedure used should extract the *total amount* (or a *proportionate* part) of the *available* form or forms of a nutrient from soils with variable properties.

2. The amount of the nutrient in the extract should be measured with reasonable accuracy and speed.

3. The amounts extracted should be correlated with the growth and the response of each crop to that nutrient under various conditions."

Bray defined available nutrients as, "those whose variation in amount are responsible for significant variations in yield and response to applied fertilizer."

Early Fertility Problems in the Everglades. The Everglades Experiment Station was created June 14, 1921, by the Legislature of the State of Florida (3) on 160 acres of Everglades peaty muck averaging between 6 and 7 feet in depth. Following numerous problems in clearing and draining the virgin muck, corn was planted in the summer of 1924 (5). Soon after germination, the corn plants began to turn yellow and ceased to grow. A large percentage of the plants in this first crop died and no grain was produced.

In 1926, fertility studies were initiated using materials such as nitrate of soda, ammonium sulfate, superphosphate, muriate of potash, and copper sulfate applied to corn. The top yield, 20.5 bushels, was produced by applying land plaster. In 1927, certain vegetable crops showed definite responses to copper and manganese sulfate, and peanuts in the presence of applied copper sulfate produced twice the yields of mineral soils. No nuts were produced in the absence of copper. Further research by Allison and others (1) proved that copper had to be applied to virgin muck in the Everglades before most crop species could survive and produce.

Early Soil Testing at the Everglades Experiment Station. During the early 1930s, a condition characterized by a yellowing of the leaves was noted in beans growing on burned-over muck. Through the diligent research of Allison, Neller, Townsend, and others (1, 6) this leaf chlorosis was found to be due to a manganese deficiency induced by high soil alkalinity which usually resulted from burning the muck, thereby, concentrating calcium in the upper few inches. It was further determined that organic soils with a pH above 6.00 would very likely produce manganese deficiency in beans. Thus, soil testing as a service to farmers was initiated by the Everglades Experiment Station. From 1932 to 1935, 1000 pH determinations were made on soil samples brought in by farmers—90 percent of these ranged from pH 5.00 to 7.00.

Soil testing as a research tool and as a service to growers started in earnest during 1939 through the efforts of Forsee and Neller (1). Initially, rapid laboratory tests for determining N, P, and K in the soil were investigated and modified to suit local requirements. Laboratory analyses of soil samples were correlated with yields of celery and grasses from fertility plots.

EXPERIMENTAL METHODS

Laboratory. When soil tests were first started, samples were analyzed for nitrate-nitrogen, phosphorus, and potassium. These elements were extracted from the soil by shaking one teaspoonful (approximately 1/180,000,000 acre) of muck in 10 ml. of 0.3 N HCl for one minute. Color intensities were developed using diphenylamine for nitrate and ammonium molybdate for phosphorus, and a turbidity with cobaltous nitrite for potassium. By visual comparisons of the color or turbidity developed by the sample with a known standard, the amount of each element extracted from the soil was estimated.

Through improvements of procedures and acquisition of better equipment, the laboratory methods have shown steady progress through the years. The bases (K, Ca, Mg, and Na) are now extracted from soil samples in 0.5 N HOAc and determined on a Beckman model DU flame photometer. P is extracted in distilled water and the intensity of the phosphomolybdate blue color determined in a Cenco colorimeter. Determinations of pH are made on a Beckman Zeromatic pH meter.

Field Experiments. Extensive fertility tests on celery, grass, beans, potatoes, cabbage, corn, etc. during the 1940s and 1950s with phosphorus, potassium, and sulfur were conducted as the basis for soil test recommendations. Most of these tests were conducted on growers' fields where the crops were subject to commercial treatment with respect to cultivation and control of diseases and insects. Most of the field tests were set up in factorial designs and usually involved 3 levels of P x 3 levels of K with or without 3 levels of S. Yields and other harvest data were recorded, and soil and stem tissue samples were analyzed for P, K, pH, and other possible variables that seemed pertinent.

Soil Sampling Technique. In order to determine the best procedure for obtaining soil samples, fertility plots comprising 1/40 of an acre were sampled at random by withdrawing varying numbers of cores per sample and analyzing each sample to arrive at the smallest number of cores required for a representative sample.

RESULTS AND DISCUSSION

Only a few of the large number of tests conducted over a period of several years to correlate soil test results with yields and plant nutrient uptake will be covered herein.

Dallisgrass. Although Dallisgrass is no longer an important pasture grass in the Everglades (it has been replaced almost entirely by St. Augustinegrass), the results obtained from a fertility test conducted in 1939 are of particular interest. These data, presented in Figure 1, show that there was a steady linear increase in yields of Dallisgrass as the amount of potassium in the soil increased. In this test there was no response in yields to added phosphorus.

Celery. More experimental work has been conducted with celery than any other vegetable crop as it is one of the most important cash crops in the Lake Okeechobee area, and removes greater amounts of plant nutrients from the soil.

In Table 1 are presented the results of an extensive experiment on celery

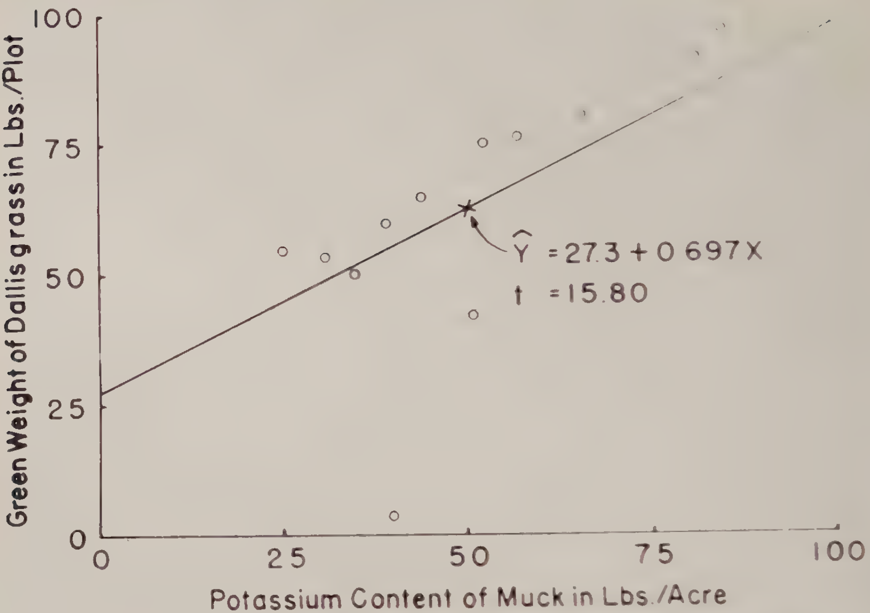

Fig. 1.—Effect of residual K in Everglades peaty muck on yield of Dallisgrass.

fertility conducted during 1945 on the Wedgworth farm near Belle Glade. The soil in this test was an Okeelanta peaty muck that had been under cultivation for several years. There was a significant response to potassium and phosphorus in yields, in soil P and K, and in uptake of P and K by the celery plants. There was also a significant increase in yields, a decrease in soil pH, and an increase in the uptake of P due to sulfur applications to the soil. Perhaps, sulfur was responsible for an increase in availability of soil phosphorus as well as some of the micronutrients.

Irish Potatoes. The results of an experiment during 1945 on virgin Everglades peat using 4 levels of P x 4 levels of K on potatoes are shown in Figures 2 and 3. These graphs show clearly the tendency for the P and K analyses curves to run parallel to the yield curves. These data also substantiate the observation that there is seldom a response to phosphorus applied to muck in the Everglades until it has been under cultivation for several years. Phosphorus is evidently fixed in an unavailable form after the muck has partly decomposed.

Cabbage. In Table 2 are presented the results of an experiment with 4 levels of P x 4 levels of K which was conducted on a thoroughly decomposed Everglades peat (pH 5.95) using cabbage as the indicator crop. There was a highly significant response in yield to phosphorus fertilization; however, there was no increase in yield due to potassium. Both P and K resulted in increases in soil P and K and in the uptake of these elements by the cabbage plants. It is interesting to note the decrease in K in the stem tissue as applied P increased.

Soil Testing. The results of analyzing a series of soil samples taken from the 0 to 6-inch soil level are presented in Table 3. It seems apparent

TABLE 1.—THE EFFECT OF PHOSPHORUS, POTASSIUM, AND SULFUR FERTILIZATION ON (A) YIELDS OF CELERY, (B) UPTAKE OF P BY CELERY, (C) UPTAKE OF K BY CELERY, (D) RESIDUAL P IN THE SOIL, (E) RESIDUAL K IN THE SOIL, AND (F) SOIL pH.

	0-K_2O			16-K_2O			32-K_2O[1]		
	0-P_2O_5	8-P_2O_5	16-P_2O_5	0-P_2O_5	8-P_2O_5	16-P_2O_5	0-P_2O_5	8-P_2O_5	16-P_2O_5
(A)									
0 lbs. S	749[2]	862	879	797	885	904	814	888	1010
500 lbs. S	819	852	946	862	889	969	855	891	930
1000 lbs. S	814	919	879	874	872	963	879	985	983
(B)									
0 lbs. S	.22[3]	.26	.28	.20	.23	.29	.24	.22	.27
500 lbs. S	.25	.26	.29	.22	.25	.28	.23	.25	.26
1000 lbs. S	.22	.26	.34	.24	.26	.29	.26	.29	.31
(C)									
0 lbs. S	8.64[3]	9.40	8.47	11.57	11.41	12.18	13.27	12.17	10.40
500 lbs. S	10.06	8.11	7.78	11.06	11.22	11.19	11.44	11.01	10.87
1000 lbs. S	9.87	8.36	8.13	11.79	10.94	11.60	12.02	11.42	11.57
(D)									
0 lbs. S	20[4]	36	46	19	33	54	23	37	55
500 lbs. S	27	32	46	19	36	47	21	32	51
1000 lbs. S	23	32	55	23	35	51	23	34	50
(E)									
0 lbs. S	164[4]	167	152	230	224	263	396	440	430
500 lbs. S	172	146	136	262	231	245	387	419	424
1000 lbs. S	165	141	145	247	237	283	416	415	410
(F)									
0 lbs. S	6.08	6.12	6.17	6.05	6.13	6.20	6.15	6.08	6.15
500 lbs. S	5.70	5.73	5.70	5.77	5.70	5.77	5.73	5.67	5.70
1000 lbs. S	5.42	5.42	5.47	5.35	5.38	5.45	5.40	5.38	5.40

[1]Applied at indicated percentages in 2000 lbs./A. of mixture.
[2]Yields are in crates per acre.
[3]P and K in stem tissue are expressed as percent of dry weight.
[4]P and K is soil are expressed as lbs./A.

from these data that 9 borings in each composite sample were sufficient to give a representation of the fertility level of an area of 1/40 of an acre.

During the vegetable growing season, from early September until late May, the Soil Testing Laboratory at the Everglades Station handles almost a capacity workload. There are, in fact, a few occasions during this period, especially at the peaks of planting time, when soil samples may accumulate for short periods of time. In Figure 4 are shown the total numbers of soil samples analyzed by this laboratory during the past ten years. The average number each year has been approximately 4,000, except during the years from 1956 through 1958 when there was a substantial increase over this number.

CONCLUSIONS

Soil testing has been of considerable benefit to vegetable growers, cattlemen, and research workers during the brief history of the agriculture of Lake Okeechobee muck soils and will continue to fulfill a very definite need.

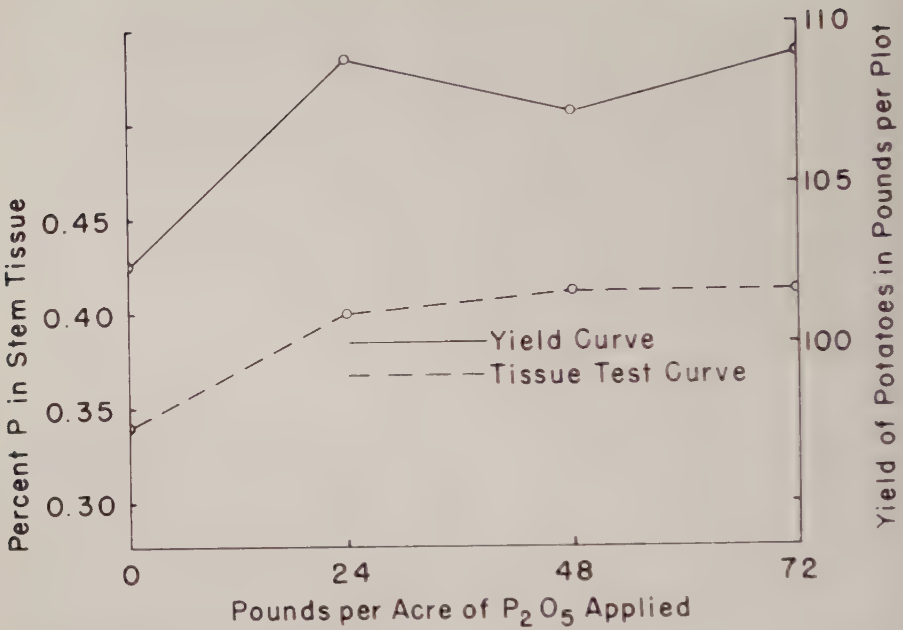

Fig. 2.—Effect of P_2O_5 applied to Everglades peaty muck on yield and uptake of P by Irish potatoes.

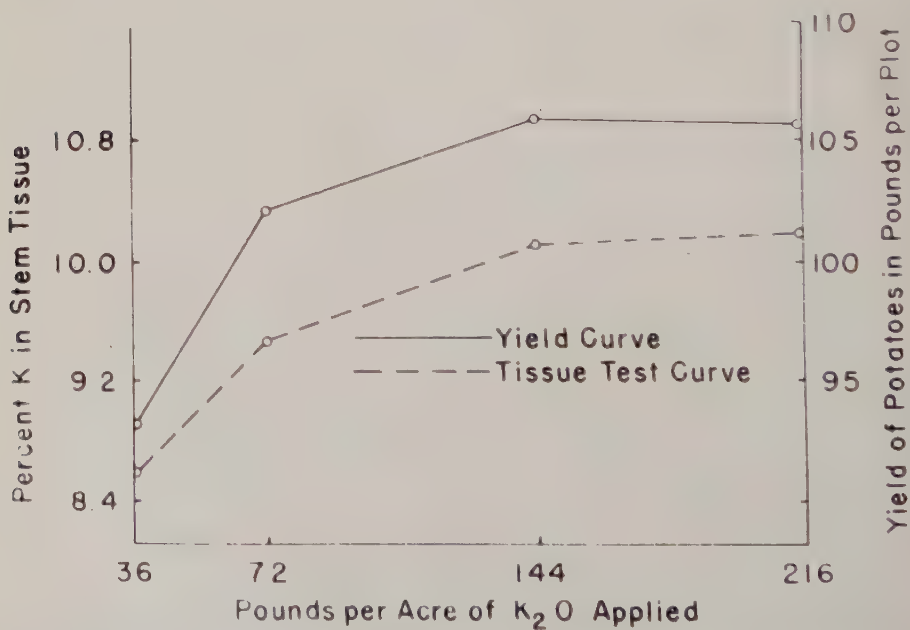

Fig. 3.—Effect of K_2O applied to Everglades peaty muck on yield and uptake of K by Irish potatoes.

TABLE 2.—THE EFFECT OF PHOSPHORUS AND POTASSIUM APPLIED TO EVERGLADES PEATY MUCK ON YIELDS OF CABBAGE, UPTAKE OF P AND K BY CABBAGE, AND RESIDUAL P AND K IN THE SOIL.

	Pounds per acre of P_2O_5 applied			
	0	30	60	90
Soil P at harvest[1]	2.3	3.1	4.0	5.0
Stem tissue P[2]	0.18	0.21	0.23	0.25
Stem tissue K[2]	4.81	4.46	4.38	4.12
Yields[3]	246	297	319	326
	Pounds per acre of K_2O applied			
	0	60	120	180
Soil K at harvest[1]	44	64	86	121
Stem tissue P[2]	0.23	0.22	0.21	0.23
Stem tissue K[2]	3.91	4.43	4.67	4.77
Yields[3]	301	287	300	302

[1]P and K in soil are expressed in lbs./A.
[2]P and K in stem tissue are expressed in percent of dry weight.
[3]Yields are expressed in number of 50 lb. bags/A.

Based on extensive research and correlation of soil test results with plant uptake of phosphorus and potassium and with crop yields, maximum yields may be expected under the fertility levels shown in Table 4. Recommendations for fertilizer use are made to bring soils of low analyses up to those levels as far as possible. Calculations as to the amount of P_2O_5 and K_2O required for this purpose are based on assuming there will be a one pound increase in the soil level of available P for every 20 pounds of P_2O_5 applied and a one pound increase in available K for every two pounds of K_2O applied. Correlations between soil applications of P and K and soil test results have supported this assumption.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. Edward King, Jr. for preparing the graphs and Mr. Ronald Jones for photographing the graphs used in this paper.

TABLE 3.—RESULTS OF ANALYSES OF COMPOSITE SOIL SAMPLES CONTAINING VARYING NUMBERS OF BORINGS FROM THE 0 TO 6 INCH LEVEL OF EVERGLADES PEATY MUCK.

Number of borings per soil sample	Pounds per Acre		
	NO_3-N	P	K
3	42	50	160
6	57	55	170
9	58	57	185
12	57	57	183
18	54	57	187
24	55	55	193

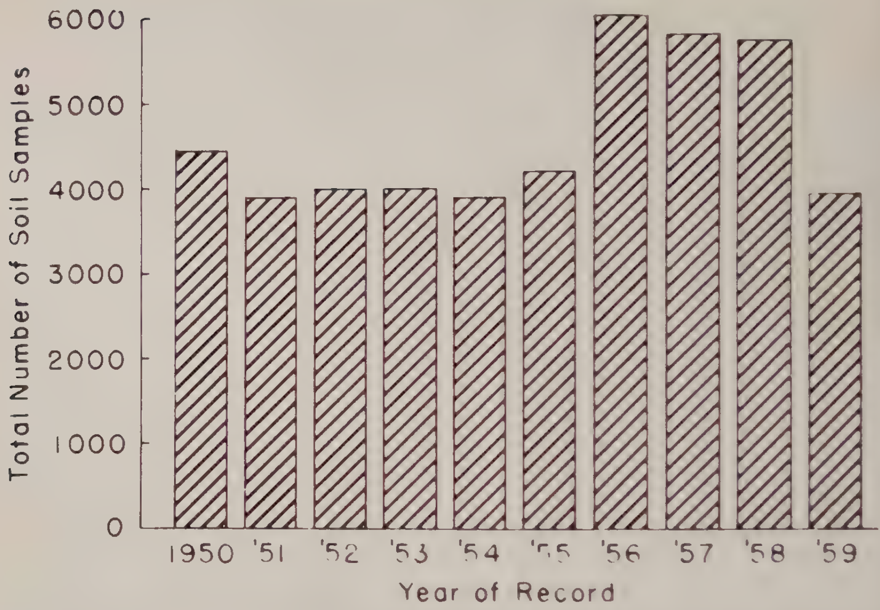

Fig. 4.—Number of soil samples analyzed by the Everglades Experiment Station Soil Testing Laboratory during the years 1950 through 1959.

TABLE 4.—SOIL REACTION AND SOIL TEST LEVELS FOR P AND K REQUIRED FOR MAXIMUM YIELDS OF REPRESENTATIVE CROPS ON PEAT SOILS IN THE EVERGLADES.

Crop	pH Value	P	K
		lbs./A.	lbs./A.
Snap Beans	Below 6.00	6-7	75-100
Potatoes	Below 6.00	10-12	150
Celery	Below 6.00	30	300
Lettuce	Below 6.00	8-10	100-150
Sugarcane	Below 6.00	7	150-200
Field Corn	Below 6.00	8-10	80-100
Sweet Corn	*	8-10	150
Cabbage	*	10	100-125
Pasture Grasses	*	5-6	80

*Research is continuing to determine the optimum soil reaction value for these crops.

LITERATURE CITED

1. Allison, R. V., A. Daane, W. T. Forsee, Jr., V. E. Green, Jr., J. R. Neller, R. E. Robertson, and F. D. Stevens. Annual Reports, Florida Agr. Exp. Sta., Projects 86 and 88, 1928 to 1955.
2. Bray, Roger H. Requirements for Successful Soil Tests. Soil Sci. 66: 83-89. 1948.
3. Florida Agr. Exp. Sta. Annual Report: 15R-16R. 1921.
4. Nelson, W. L., J. W. Fitts, L. T. Kardos, W. T. McGeorge, R. O. Parks, and J. Fielding Reed. Soil Testing in the United States. Prepared by: The Soil Test Work Group of the National Fertilizer, Soil and Fertilizer Research Committee. U. S. Govt. Printing Office. 1951.
5. Tedder, George E. Annual Report, Florida Agr. Exp. Sta. 130R-136R. 1924.
6. Townsend, G. R. Annual Report, Florida Agr. Exp. Sta. Project 125. 1934.

Research on Soil Testing and Its Application for Vegetable Crops on Mineral Soils

R. B. FORBES[1]

The objective of this portion of the symposium is to present the current status of research in soil testing and the present application of soil testing in the culture of vegetable crops on the mineral soils of Florida.

Since Dr. NeSmith (3) has so ably covered the development and history of soil testing in Florida, we will not go into this aspect of the subject other than to point out that the present state has come, not overnight, but through years of steady research and progress (4).

In the leading vegetable growing regions of Florida, several different systems for soil testing have been or are being evolved. These systems vary somewhat depending on factors such as soil type, crops grown, equipment available, or the peculiar problems of the area.

The Soil Testing Laboratory at the Main station in Gainesville is the largest in the state and is widely used by vegetable growers. This laboratory has operated since July, 1959 as an Extension Service function but remains active in the research field through a close working agreement with experiment station personnel. A number of research projects are being conducted in cooperation with other departments and sub-stations. Dr. Locascio of Vegetable Crops and Dr. Breland of the Soils Department, together with Dr. NeSmith's help at the Soil Testing Laboratory, are running studies with various vegetables to correlate crop yields with soil analyses on different soil types. Another example of this cooperative research is the potato fertility study conducted last year by Dr. Myhre and co-workers at Hastings with analyses furnished by the Gainesville laboratory.

As a result of research done in the past, Dr. Montelaro, Associate Vegetable Crops Specialist, in cooperation with research workers at the main station and branch stations, compiled a mimeographed guide on interpretation of soil test values for vegetable crops. This guide has gone out to the county agents for their use in planning fertilization programs for vegetable growers. At present, fertility-yield correlation values for a number of vegetable crops are not as complete as would be desirable. Even so, the guide provides an indication of needed levels of nutrients. It is proving a valuable tool in everyday use by county agents in the interpretation of soil test results on samples they have submitted from local farms.

The Everglades Station has many years of soil test and correlation data on the organic soils using their own specialized methods, somewhat different from those of the Soil Testing Laboratory in Gainesville. Dr. Forsee[2] has agreed with the Gainesville laboratory to run analyses and make recommendations for crops on the Everglades and other peat soils from which samples are received. It is recommended that soil samples from sands, from South Florida or elsewhere, be sent to Gainesville for recommendations made on the basis of their tests.

Dr. Forsee also reports that considerable fertility work with vegetables

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[2]Personal communication with author.

on sandy soils has been accomplished at the Plantation and Indian River Field Laboratories. However, the correlation work has not been as complete as that on the organic soils. Should correlations work be undertaken on the sands in the future, it was indicated that chemical procedures similar to those used at the Soil Testing Laboratory in Gainesville would be used. This would make it possible for better interpretation of soil test results from sandy soils sent in to Gainesville by county agents from that area.

The Gulf Coast Experiment Station has conducted much soil test research on the mineral soils of that area. In recent years Dr. Geraldson has developed the principle of *intensity* and *balance* of plant nutrient elements in the soil as a guide for fertilization of vegetable crops. *Intensity* is defined as a measure of the concentration of total soluble salts in a soil solution. *Balance* is a measure of relative proportions of the various fertilizer elements in the growth medium. While balance determinations require a well equipped analytical laboratory for determination of individual nutrient elements, intensity may be quickly estimated with simple procedures on an inexpensive conductivity bridge (1) (2). A mimeographed guide (2) giving procedures for determination of intensity and interpretation of results for 18 different vegetables was prepared by Extension Vegetable Crops Specialists and Dr. Geraldson for information of county agents and others interested. A number of county agents have been developing the application of this research to local needs in keeping a check on the total fertilizer status of a soil. This work, besides being of value in recognizing deficiencies, shows the excessive ranges of concentration of salts. This feature should prove of special value in areas where buildup of salts often occurs from either excessive fertilization or brackish irrigation water.

For the Dade County farming area of calcareous soils, Dr. Paul G. Orth[3] of the Sub-Tropical Experiment Station at Homestead has summarized the present status of soil testing. Mr. W. R. Llewellyn, Assistant County Agent, is engaged in soil testing and making recommendations. Water is used as an extractant and appears adequate, although research to find a better extracting solution is needed for available phosphorus. Dr. Orth points out that the shallow Rockdale soil is more difficult to evaluate by soil testing than the marl soil. Factors affecting fertilizer utilization and efficiency need more study for both soils. Plant tissue testing gives promise of being a useful tool. Work to evaluate this approach is now in progress. The determination of chlorides has proven very useful in evaluation of salt intrusion. Adequate interpretation standards have been established for chlorides on these marl soils.

The Central Florida Experiment Station at Sanford has for years been doing a considerable amount of soil testing for local growers. Routine analyses include pH and soluble salts. In special cases chlorides, nitrates, or copper may be run. Samples requiring more complete analyses are sent to the Gainesville laboratory. Dr. Westgate (5) has found the conductivity bridge to be most useful in this area where build-up of salts from salty irrigation water or excessive fertilizer is a common occurrence. Experiments have been run to determine optimum and excessive ranges encountered with various vegetables (7). The quick determination of soluble salts has been a big aid for celery growers in achieving optimum nutritional levels while avoiding the excesses that lead to blackheart (6) (8). Experi-

[3]Personal communication with author.

ments have been conducted for correlation of individual nutriment levels with crop response (7). Continued cooperative work between this station, the main station, and the Soil Testing Laboratory is assured.

This report would be incomplete without some mention of the commercial soil testing laboratories.. As a group, without giving special credit to any one, these commercial organizations can be said to have a definite place in Florida's vegetable production picture. Some are equipped to render special services and give individual attention to growers with particular problems (9)

In conclusion, certain facts stand out. First there is the need for more correlation data. Another is the beneficial effect of the present Soil Testing Laboratory at Gainesville and its work with the extension agents all through the state. The usefulness of the specialized farming area laboratories at Belle Glade on the peat and at Homestead for the marl and rockland soils is still apparent. One outstanding point is the close working agreement between research and extension personnel in regard to these soil testing laboratories. This should lead to benefits for both research and extension as well as for all of the vegetable growers of the state.

LITERATURE CITED

1. Geraldson, C. M. Soil soluble salts—determination of and association with plant growth. Fla. State Hort. Soc. Proc. 70: 121-126. 1957.
2. Montelaro, J., *et al.* Vegetarian. Dept. of Veg. Crops, Univ. of Fla. Agr. Ext. Serv. Nov. 9, 1959.
3. NeSmith, J. History and present status of soil testing in Florida. Soil and Crop Sci. Soc. Fla. Proc. 20: This issue 1960.
4. Volk, G. M., *et al.* Symposium: Soil and tissue testing. Soil Sci. Soc. Fla. Proc. 13: 89-148. 1953.
5. Westgate, P. J. Effects of soluble salts on vegetable production at Sanford. Fla. State Hort. Soc. Proc. 63: 116-123. 1950.
6. Westgate, P. J., W. G. Blue, and C. F. Eno. Blackheart of celery and its relationship to soil fertility and plant composition. Fla. State Hort. Soc. Proc. 57: 158-163. 1954.
7. Westgate, P. J. and R. B. Forbes. Major nutrients on celery. Fla. Agr. Exp. Sta. Annual Report pp. 180-182. 1957.
8. Westgate, P. J. and R. B. Forbes. Soil management problems in vegetable crop fields. Fla. Agr. Exp. Sta. Annual Report pp. 196-197. 1959.
9. Wolf, B. Commercial laboratory and advisory procedures in subtropical agriculture. Agricultural and Food Chemistry *8*, no. 2: 96-99. 1960.

Some Considerations Pertaining to the Use of Soil Analyses in Citrus Production[1]

W. F. SPENCER[2]

Many soil samples from citrus groves are analyzed each year in the hope that the information will be useful in predicting the need for fertilizers and soil amendments and in diagnosing adverse tree conditions. Generally, the objectives of soil testing are as follows: (1) To determine the amount of reserve nutrients in the soil in order to assess their degree of sufficiency for optimum growth of the crop in question; (2) To determine the presence of toxic amounts of nutrients or other constituents in the soil; (3) To determine the soil pH or some other soil factor which influences the availability of the measured nutrient or degree of toxicity of a toxic constituent.

The ability of a soil to maintain fairly large reserves is very important from the standpoint of soil testing. Bray (1) separated the nutrients into mobile and immobile nutrients. The immobile nutrients are those which tend to accumulate in the soil and for which soil testing is most applicable. Volk (18) also separated the nutrients on the basis of their leachability and outlined the objectives of soil and tissue analyses under Florida conditions.

Most Florida citrus is grown on sandy soils which are low in cation exchange capacity (8). The following discussion on soil testing is primarily applicable to sandy, well drained soils such as Lakeland and Blanton fine sands and other more poorly drained soils of approximately the same nutrient holding capacity. Some modifications may be necessary in the interpretation of soil tests for calcareous soils. Soil testing on citrus will be discussed from the standpoint of the relatively immobile elements which accumulate in the soil, the relatively mobile elements which do not accumulate in the soil in appreciable quantities, and lime requirement as reflected by soil pH and calcium.

RELATIVELY IMMOBILE ELEMENTS

The relatively immobile elements are those added in citrus fertilizers or sprays which tend to accumulate in the soil and consequently can be maintained at sufficiently high levels so that further additions are not immediately necessary. This category includes the nutrient elements phosphorus, copper, and manganese, and other soil constituents which may accumulate in significant amounts.

Phosphorus.—Several studies (2, 9, 11, 13, 15) have shown that applied phosphate accumulates in sandy soil in an available form. Since the average crop of fruit removes only approximately 20 pounds of P_2O_5 per acre, it is possible to build up large reserves of phosphorus.

Soil test correlation work is being conducted at the Citrus Station with the purpose of establishing a level for soil phosphorus above which no

[1]Florida Agricultural Experiment Station Journal Series, No. 1245.
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response would be expected from further phosphate additions. Soil test values below this level would not necessarily indicate that a response will always be obtained from phosphate fertilizers applied to such soils. A large number of soil samples obtained from experimental sites, groves and unfertilized areas were analyzed for phosphorus extractable with three solutions, including acid ammonium acetate—the extractant used at the Florida Soil Testing Laboratory. These data indicate that a phosphorus soil test level of 50 pounds P_2O_5 per acre extractable with acid ammonium acetate would probably be a limit above which no response would be expected from phosphorus fertilization. This "critical level" may result in a few groves being unnecessarily fertilized with phosphate but this is more desirable than risking a deficiency. When making fertilizer recommendations for phosphorus on the basis of a soil test, it is necessary to include a large factor of safety in interpretation of the test. This follows from the fact that the cost of fertilizer saved is only a small part of the cost of production, and the potential loss in income is great relative to the small cost of the fertilizer. With a relatively high income crop such as citrus, fertilization should be at such a sufficiently high level so that no element is significantly deficient.

The writer found that considerable quantities of applied phosphorus moved from the surface six inches of soil, but essentially the entire amount was retained within the rooting zone of the citrus trees (15). The extent of movement was somewhat dependent on soil pH but the greatest accumulation of phosphorus occurred within the 12-36 inch subsoil zone. This fact would indicate that a subsoil sample might be helpful in evaluating the phosphorus status of soils in citrus groves. Fractionation of the accumulated phosphorus (15) indicated that the major portion was retained in an ammonium fluoride extractable form. Other soil analyses have indicated that the amounts of phosphorus extractable with ammonium fluoride were highly correlated with the amounts of phosphorus added in fertilizers. Since sandy soils planted to citrus are fairly uniform in their phosphorus behavior, ammonium fluoride extractable or even total phosphorus which reflects the amount of phosphorus added, may prove to better assess the phosphorus supplying power of the soil than the presently used acid-ammonium acetate extractant.

High phosphorus in the soil may have unfavorable effects, such as lower soluble solids in the juice of the fruit (9), inhibited root growth (13, 16) and lessened cold hardiness (16). These are sufficient reasons for discontinuing the use of phosphate fertilizers when the soil level has reached a sufficiently high concentration.

Copper.—It is possible to build up the copper content of the soil so that it is not necessary to apply additional copper to meet the nutritional requirements of citrus trees. Soil analyses by Wander (22) and Reuther and Smith (10, 11) indicate that applied copper is largely retained in sandy soils and may exhibit beneficial or harmful properties, depending on the amount present in the soil. Reuther and Smith (10) concluded that the level of soil copper in many mature Florida citrus groves on acid sandy soil is high enough to induce foliage chlorosis and cause damage to normal root development if the soil is allowed to become too acid.

A rapid test for excesses of copper in sandy soils was developed to detect potentially toxic quantities of copper in the soil (14). This test is being used to evaluate toxicity problems and not to determine deficient

levels since it was not designed to measure small amounts at low or deficient soil copper concentrations. If the test indicates more than 150 pounds copper per acre in an acid sandy soil, copper is high enough to be potentially toxic. In these cases the soil pH should be maintained above 6.0 by liming and in groves containing exceptionally high amounts of copper it may be beneficial to maintain the pH above 6.5. For sandy soils, 50 pounds copper per acre has been arbitrarily established as a level above which a response to additional copper would not be expected.

Since the copper level of the soil will not decrease appreciably, it is not necessary to analyze the soil for copper each year. For older groves with high accumulations of copper, one soil analyses should be sufficient to warn the grower that the pH should be maintained at an adequate level for many years in the future. For younger groves which are still receiving copper applications, a copper test should be run periodically, possibly every five to ten years, to check on the amount of copper being accumulated. This could also be accomplished by a bookkeeping system whereby the grower keeps a record of the copper being applied.

Manganese.—Manganese accumulates in acid soils, especially when the soil pH is adequately maintained (22, 10, 11). Its availability is highly pH dependent. These facts indicate that a soil test for manganese could be developed and a level of soil manganese established, at various pH levels, above which a response to additional manganese would not be expected. In this case, as with copper, total analysis would probably be satisfactory since essentially the total amount present in the soil is that which has accumulated from fertilizer applications. However, an accurate interpretation cannot be made of soil manganese levels in citrus groves until the optimum level of manganese in sandy soil planted to citrus has been established.

RELATIVELY MOBILE NUTRIENTS

Relatively mobile nutrients applied in citrus fertilizers which do not accumulate in the soil in appreciable amounts are nitrogen, potassium, magnesium and boron. On the basis of our present knowledge of soil-plant relationships, soil tests for these elements appear to be of very doubtful value. As pointed out by Volk (18), with large reserves such as can be obtained with phosphorus, it is possible to set a large factor of safety for an element in interpreting soil tests. On the other hand, the soil reserves of a nutrient such as potassium or nitrogen are quite low and these reserves must be supplemented by fertilization to meet the crop needs for the nutrient. Maximum use of this small reserve can be made only by reducing the nitrogen or potassium recommendation to less than the standard recommendation. Therefore, the benefits are small compared to the possible loss in yield due to a shortage of the nutrient. Fertilization with mobile nutrients should be at a level sufficient to prevent any measurable deficiencies and is probably best controlled by a standard fertilization program (12) based on results from rate experiments. The key to the problem with citrus, as with other crops (18), lies in determining a factor of safety sufficient to cover soil variation and variation in amounts of nutrient with time of year and other factors and then to determine if this is sufficient improvement over a standard fertilizer recommendation to justify the use of the soil test. In the case of the mobile nutrients, any doubtful improvement does not seem to justify the added expense of a soil test.

Nitrogen.—Soil tests for nitrogen are of two general types—those which measure the amount of nitrogen potentially available through mineralization of the nitrogen in the organic matter and those which measure the amount of inorganic nitrogen carried over or remaining from previous fertilizer additions. The amount of nitrogen released from sandy soils low in organic matter is extremely small compared with the amount needed by citrus. Therefore, any nitrogen soil test employing incubation procedures which measure potential nitrogen release, would have little value in predicting nitrogen needs of citrus growing on sandy soils.

Nitrogen tests which measure carry-over from previous fertilizer additions are equally of little value. Nitrogen is probably the most mobile element in all soils, but during dry periods of the year, certain amounts may accumulate even in sandy soils. If soils in citrus groves were analyzed for nitrogen carry-over before each fertilization, the analyses might indicate the amount of the fertilizer nitrogen which had not been removed from the surface six inches of soil.. However, the question arises, can the next fertilization safely be reduced by the amount found in the soil just prior to fertilization? On the basis of our present knowledge, a reduction of the current application because the nitrogen from the last application was not yet completely utilized would appear unjustified. The trees possibly need the entire annual application regardless of the amount of nitrogen in the soil at any one time. In the case of citrus, the nitrogen status of the tree at time of sampling must also be considered. The amount of nitrogen in the soil may reflect the status of the nutrient in the tree or it may reflect the exact opposite, depending on the efficiency of utilization of the previously applied nitrogen. This is not the case for soil nitrogen analyses on field crops or vegetables where a new crop is planted following the analyses.

Potassium.—Most of the above comments on inorganic nitrogen also apply to soil analysis for potassium. Postassium is a fairly mobile nutrient in most of the sandy soils planted to citrus in Florida and acts more like nitrogen than the more immobile nutrients such as phosphorus, copper and manganese (4, 5, 7, 21). The extreme variation in extractable soil potassium throughout the year in the same grove was shown by Wander (21). These data would indicate that a soil test for potassium on sandy soils would be of little value in predicting the amount of fertilizer potash needed for citrus. As with nitrogen, a tree can maintain its own reserve potassium supply by luxury feeding and a soil test for potassium at any time during the year may or may not indicate the potassium status of the tree. If soil analyses for mobile nutrients such as potassium have a place in citrus production, it would be in conjunction with leaf analyses to determine the nutrient status of the trees as well as the soil.

Magnesium.—Magnesium leaches rapidly from most sandy soils planted to citrus even though it is not quite as mobile as nitrogen and potassium. Therefore, analyses for magnesium are subject to somewhat the same limitations as analyses for potassium. Magnesium analyses are further complicated by the fact that dolomite contains magnesium. Since most growers use dolomite as a liming material, the amount of magnesium extracted by acid ammonium acetate will be directly related to the amount of unreacted dolomite as well as the amount of immediately available magnesium in the soil.

Peech (6) attempted to correlate neutral ammonium acetate extractable magnesium with the occurrence of magnesium deficiency symptoms in citrus

groves. His data indicated that it would be difficult to predict, even at high soil magnesium levels, whether or not deficiency symptoms would appear in a particular grove on the basis of the extractable soil magnesium level only.

Most long-term field experiments on citrus are unsuitable for soil test correlation purposes because they receive regular applications of the nutrients. Thus, the soil nutrient level is changing each year and the experiments are evaluating the effect of a fertilizer program on soil level and fruit yield and not the effect of soil level, per se, on yield. For example, Spencer and Wander (17) reported a positive correlation between soil magnesium and the magnesium content of citrus leaves. A low apparent critical soil magnesium level of 40 pounds Mg per acre from the application of Emjeo resulted in an ample leaf magnesium content. This apparent critical level associated with the high leaf Mg level was a reflection of soil level plus fertilizer magnesium added three times each year. It would be misleading to say that a soil test level of 40 pounds magnesium per acre resulted in no magnesium deficiency when it was the high level of fertilizer magnesium added as magnesium sulfate which resulted in an adequate leaf magnesium level and only incidentally in the 40 pounds per acre soil magnesium.

As reported by Wander (21) the extractable soil magnesium varies from month to month in the same plots. Therefore, a specific soil magnesium level may or may not result in a definite amount of magnesium deficiency or leaf magnesium, depending upon the soil sampling date, crop strain, leachability of the magnesium and any other factor effecting magnesium uptake from the soil. Such a large safety factor is necessary to use the test in the prediction of the need for fertilizer magnesium that the practical value of a soil test for magnesium, is questionable.

In evaluating a fertilizer program for magnesium, leaf analysis is probably a more helpful guide in predicting when excessive magnesium is being used than is soil analysis. On the deficient side, the appearance of traces of magnesium deficiency leaf patterns may be adequate warning to a grower to increase the magnesium level in his fertilizer program. Conversely, the complete absence of deficiency symptoms indicates the trees are being supplied with sufficient magnesium.

Boron.—Boron is applied as a maintenance application either in the fertilizer or in nutritional sprays. It does not accumulate in the soil and a routine soil test for boron under these conditions would have little application.

SOIL pH AND CALCIUM

Soil pH is essentially a measure of soil condition as it greatly influences the availability of nutrients in the soil. Peech (7) first pointed out the value of lime in making the limited exchange capacity of most sandy soils planted to citrus more effective in holding nutrient bases. For a recent discussion of soil acidity and liming effects, see Volk (19).

There are many benefits to be derived from maintaining the soil pH with lime (20). Soil acidity arises from leaching and crop removal of basic nutrients, using fertilizer materials leaving acid residues and using sulfur for pest control. All these materials are applied directly or indirectly to the surface of the soil. Therefore, it is of importance that the pH of the surface soil be maintained so that these materials can be neutra-

lized in the surface before they leach into the subsoil and unfavorably affect the subsoil pH. Maintaining the soil pH in the range 5.5 to 6.5 increases the availability of phosphorus and indirectly the availability of the basic nutrients, magnesium, potassium, and calcium by preventing their rapid leaching from the soil. Soil pH also affects the availability or toxicity of copper and other minor elements which may be present in high amounts.

Soil samples should be taken once each year for determination of soil pH and possible need for the addition of liming material. The time of the year that this sample is taken is not of great importance. However, prefertilization samples are best so that the soil pH is not greatly influenced by fertilizer. It is recommended that the soil pH be maintained between 5.5 and 6.5 by periodic applications of dolomite or limestone (12). Therefore, if the pH is below 5.8, one ton of liming material per acre should be applied, unless the soil contains a potentially toxic level of copper. If a sandy soil contains 150 pounds per acre of copper or more, it indicates that copper in the soil is high enough to cause trouble under the right conditions. In this case, the soil pH should not be allowed to drop below 6.0 and a pH reading below 6.2 indicates a need for lime. For soils with a much higher exchange capacity than Lakeland fine sands, more lime may be required than one ton per acre to obtain the desired pH.

Normally, a soil pH determination gives an indication of the calcium level of the soil and can be relied upon to indicate a need for liming materials. However, due to different types of soil colloids and the presence of bases other than calcium, it may be possible to have a pH in the optimum range and a calcium level below the optimum range for citrus in some soils of low nutrient holding capacity. Since this unusual condition may prevail, an extractable soil calcium level has been arbitrarily established below which lime or dolomite is recommended to supply calcium even though the soil pH appears to be in the optimum range. This value will undoubtedly vary, depending upon the exchange capacity of the soil. However, if the amount of calcium extractable in acid ammonium acetate is less than 300 pounds calcium per acre in the sandy soils of the Ridge area, such as Lakeland fine sand, it is recommended that dolomite or other liming material be applied to furnish calcium regardless of the soil pH. If calcium levels are above 300 pounds per acre, the possibility of a calcium deficiency for citrus is rather remote and pH measurements should be relied upon to indicate the need for dolomite or lime. In this regard, it should be recognized that the soil pH determination is much more accurate than the determination of extractable soil calcium, thus it would be desirable to re-analyze the soil before applying liming material on the basis of the calcium level only.

DISCUSSION

The problem of soil testing for citrus is not one of a decision as to whether the soil should be tested or not, but rather one of making a decision concerning the type of analysis justified for the various elements and soil conditions. Citrus production on Florida's acid sandy soils would appear to benefit from soil tests for pH and possible reserves of certain immobile nutrients which can be accumulated in large amounts. Citrus production also lends itself to the use of a fertility program in which the use of all the mobile nutrients are covered by a standard set of recommendations. If only the fertility program approach were used in making fertilization and

soil amendment additions, there would be no control of pH or interfering excess and there would be inefficient use of large soil reserves.

The value of any soil test depends upon the soil sample adequately representing the area samples. Soil samples for citrus should be obtained from the 0-6 inch level near the drip of the tree branches. A sample should be a composite of at least 15 individual cores with two or more composites submitted to the soil testing laboratory from each sample area. A subsoil sample from the 12-24 inch depth may provide useful information to evaluate phosphorus accumulations.

Soil samples for pH control should be taken annually. This sample can be analyzed for soil calcium as well as pH to help in the prediction of the need for lime. Analyses of soil samples for the immobile nutrients, phosphorus and copper, would be required only once every several years. In these cases, after the copper or phosphorus level has been determined, there will be very little change, except for increases due to fertilizer or spray additions.

The present recommended level of 50 pounds P_2O_5 per acre or above appears to be a safe level above which a response to phosphorus fertilizer is unlikely. Phosphate field experiments and research on other soil phosphorus tests now in progress may pinpoint this critical phosphorus level more accurately.

It is possible that soil tests for potash will prove useful on the more retentive calcareous mineral soils on the east coast of Florida. Hunziker (3) reported that the optimum soil potassium level of citrus groves in the Indian River area appeared to be influenced by the exchange capacity of the soil. Possibly a comprehensive study of the effect of exchange capacity on desirable potassium levels would result in a few soils being placed in the potassium accumulating category.

The use of uniform methods of analyses by all soil testing laboratories analyzing soils for growing the same crop, as proposed by Breland and NeSmith,[3] should result in making soil testing more useful to the Florida growers. It would be another step forward if somewhat the same interpretations were applied to the results of these soil tests. This would lead to less confusion on the part of the growers and a wider use of the soil analyses which have proven to be of value in the past.

SUMMARY

Soil pH and total copper determinations continue to be the most useful tests on sandy soils planted to citrus. Extractable soil calcium values are useful in some cases in evaluating the need for liming materials. Soil phosphorus indicates the extent of phosphorus accumulations from past fertilizer additions. Extractable soil phosphorus has not been accurately correlated with response to fertilization, but a level has been established above which a response to phosphorus fertilization is extremely unlikely. Other soils tests are of doubtful value, especially on the lighter sandy citrus soils. Soil tests for the mobile nutrients such as nitrogen, potassium, magnesium and other elements which leach readily from the soil can, at times, be misleading and other guides are much more useful in determining fertilizer needs for these elements.

[3]Personal communication.

LITERATURE CITED

1. Bray, R. H. Correlation of soil tests with crop response to added fertilizers and with fertilizer requirement. In Diagnostic Techniques for Soils and Crops. American Potash Institute, Washington 6, D. C. pp. 53-86, 1948.
2. Bryan, O. C. The accumulation and availability of phosphorus in old citrus grove soils. Soil Sci. 36: 245-249, 1932.
3. Hunziker, R. R. The relationship of soil potassium and leaf potassium status to yield of citrus in the Indian River area. Proc. Fla. State Hort. Soc. 73: In press, 1960.
4. Jamison, V. C. Practical considerations related to pH control in sandy soils planted to citrus. Proc. Fla. State Hort. Soc. 55: 28-33, 1942.
5. Kime, C. D., Jr. Leaching of potash from a sandy citrus soil of Florida. Proc. Fla. State Hort. Soc. 56: 43-48, 1943.
6. Peech, M. Determination of exchangeable magnesium in soils by titan yellow with reference to magnesium deficiency in citrus. Soil Sci. Soc. Am. Proc. 4: 189-195, 1939.
7. Peech, M. Availability of ions in light sandy soils as affected by soil reaction. Soil Sci. 51: 473-486, 1941.
8. Peech, M. and T. W. Young. Chemical studies on soils from Florida citrus groves. Florida Agr. Exp. Sta. Bul. 448, 1948.
9. Reuther, W., F. E. Gardner, P. F. Smith and W. R. Roy. A Progress report on phosphate fertilizer trials with oranges in Florida. Proc. Fla. State Hort. Soc. 61: 44-60, 1948.
10. Reuther, W. and P. F. Smith. Toxic effects of copper on growth of citrus seedlings and its possible relation to acid soil chlorosis in Florida citrus groves. Citrus Magazine 14 (11): 25-27, 1952.
11. Reuther, W. and P. F. Smith. Iron chlorosis in Florida groves in relation to certain soil constituents. Proc. Fla. State Hort. Soc. 65: 62-69, 1952.
12. Reitz, H. J., C. D. Leonard, Ivan Stewart, W. F. Spencer, R. C. J. Koo, E. J. Deszyck, P. F. Smith and G. K. Rasmussen. Recommended fertilizers and nutritional sprays for citrus. Florida Agr. Exp. Sta. Bul. 536-A, 1959.
13. Smith, P. F. Effect of phosphate fertilization on root growth, soil pH, and chemical constituents at different depths in an acid sandy Florida citrus soil. Proc. Fla. State Hort. Soc. 69: 25-29, 1956.
14. Spencer, W. F. A rapid test for possible excesses of copper in sandy soil. Florida Agr. Exp. Sta. Bul. 544, 1954.
15. Spencer, W. F. Distribution and availability of phosphate added to a Lakeland fine sand. Soil Sci. Soc. Am. Proc. 21: 141-144, 1957.
16. Spencer, W. F. Effects of heavy applications of phosphate and lime on nutrient uptake, growth, freeze injury, and root distribution of grapefruit trees. Soil Sci. 89: 311-318, 1960.
17. Spencer, W. F. and I. W. Wander. A comparison of magnesium sources for young orange trees. Proc. Fla. State Hort. Soc., in press, 1960.
18. Volk, G. M. Objectives of soil and tissue analysis. Soil Sci. Soc. Fla. Proc. 13. 89-100, 1953.
19. Volk, G. M. Soil acidity and liming. Soil and Crop Sci. Soc. Fla. Proc. 19: 66-72, 1959.
20. Volk, G. M. and C. E. Bell. Soil reaction (pH). Florida Agr. Exp. Sta. Bul. 400, 1944.
21. Wander, I. W. The effect of calcium phosphate accumulation in sandy soil on the retention of magnesium and manganese and the resultant effect on the growth and production of grapefruit. Proc. Am. Soc. Hort. Sci. 55: 81-91, 1950.
22. Wander, I. W. The total manganese, copper, and zinc content of soils used for citrus production in Florida. Soil Sci. Soc. Fla. Proc. 14: 27-36, 1954.

Results of Research on Soil Testing and Their Use as Guides to Liming and Fertilization for Production of Field Crops

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Soil testing at the University of Florida has undergone many changes in the last 23 years, during which time I have had the privilege of serving in various capacities in each of the three divisions of its College of Agriculture. As might be expected, my interest in soil testing varied as my assigned duties changed.

From the time of my appointment as an assistant chemist in the Department of Chemistry and Soils of the Experiment Station in 1937 until I became Agronomist with the Extension Service on a part-time basis, in 1947, I had little reason to be concerned with soil testing.

At the time I assumed responsibility for strengthening the Extension program in field crop production, my Station duties were changed to include handling correspondence on all soil samples submitted to the laboratory from areas in which field crops were to be grown. Naturally, I soon recognized a real need for correlated information on which liming and fertilization recommendations could be based.

Meanwhile, the Department of Chemistry and Soils had become the Department of Soils in 1939, F. B. Smith had been named head of the Department on January 1, 1945, and "Testing of Soils and Limestone" had become an official Station project on July 1, 1945, with Smith as project leader. Under this project, soil-testing procedures were changed to include, in addition to electrometric measurement of pH values, estimation of calcium, magnesium, phosphorus, potash, and nitrate nitrogen by semi-quantitative methods.

Unfortunately, these methods had not been properly calibrated under Florida conditions, and analytical results had not been correlated with nutrient applications and crop response. As a consequence of this situation, soil-test results, except pH values, largely were ignored when making liming and fertilization recommendations.

Everyone concerned with this soil-testing program recognized clearly some acute needs, which included the following: (1) better methods of analysis, (2) correlation of analytical results with nutrient applications and crop response, and (3) development of a set of liming and fertilization recommendations based on such correlations. These needs have received major attention since July 1, 1952, at which time H. L. Breland was placed in charge of the Soil Testing Laboratory, W. L. Pritchett was delegated responsibility for development of a sound basis for interpretation of soil-test results, I became Extension Agronomist on a full-time basis, and the three of us began a cooperative program of field trials and related studies.

On the basis of studies by Breland, the analytical procedures now used in the Soil Testing Laboratory were adopted in 1953. During the next two years, Pritchett and the Extension agronomists conducted numerous field tests with each of several major field crops on different kinds of soil.

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for the purpose of correlating the results of analysis by these procedures with nutrient applications and crop response.

In these field tests, pH, calcium, magnesium, phosphorus, and potash levels were determined on soil samples taken just prior to fertilization; nitrogen, phosphorus, and potash were applied at various rates; crop yields were measured; and the yield data were correlated with the results of soil analysis.

These correlation studies led to recognition of low, medium, and high levels for pH, calcium, magnesium, phosphorus, and potash, and to development of a set of tentative recommendations for liming and fertilization on the basis of the levels found.

To test the interpretation of soil-test results developed from the studies just described, an intensive program was carried out in 1957 in four counties, representing the major soil and field crop combinations in Florida.

The success of the trial program in these four counties indicated the desirability of intensifying the soil-testing program throughout the general-farming area of northwestern and northeastern Florida.

In the fall of 1958, farmer meetings were held in twelve counties in the general-farming area. These meetings, and the follow-up activities, resulted in substantial increases in the number of soil samples tested and also in the consumption of lime, mixed fertilizers, and nitrogen, but no significant shift toward use of the recommended grades of mixed fertilizer. No doubt, the recommended grades would have been more widely used if they had been readily available.

At a meeting in August of 1959, representatives of several Florida fertilizer companies agreed to manufacture, and supply through their salesmen and dealers, all the grades of mixed fertilizer required for fertilization of field crops on the basis of soil-test results. The industry group also agreed to support an intensive soil-fertility program, in connection with the production of field crops, in the 30-county general-farming area of northwestern and northeastern Florida. At the same time, it was agreed that use of soil testing as a diagnostic tool would be continued in counties outside the general-farming area. Pastures are the major field crop in most of those counties.

Meanwhile, the Soil Testing Laboratory had been transferred from the Experiment Station to the Extension Service, and the county agents had been throughly trained and given full responsibility for making liming and fertilization recommendations on the basis of soil-test results.

Meetings for both dealers and farmers were held throughout the general-farming area in the fall of 1959. The leaders of the Extension projects in Agronomy and Soils assisted the county agents with many of these meetings and presented county figures on use of, and need for, fertilizers and lime. Following these meetings, the county agents were furnished kits of information for use in preparation of timely newspaper releases and spot radio announcements.

Farmer response to these activities was exhibited in increases in the number of samples submitted for analysis, in increases in the use of lime, mixed fertilizers, and nitrogen, in a significant shift toward use of the recommended grades of mixed fertilizer, and in an increase in the average nutrient content of the mixed fertilizers used. As an example of this response, farmers in Suwannee County used 33 percent more nitrogen, 46 percent more phosphorus, and 103 percent more potash in mixed fertilizers

TABLE 1.—CLASSIFICATION OF SOIL-TEST RESULTS.

Rating	pH	Nutrient Levels, Pounds per Acre			
		CaO	MgO	P_2O_5	K_2O
Low	<5.5	<450	< 75	<10	< 60
Medium	5.5-6.5	450-900	75-150	10-20	60-120
High	>6.5	>900	>150	>20	>120

TABLE 2.—LIMING FOR FLORIDA FIELD CROPS, ON BASIS OF SOIL-TEST RESULTS.*

A. Tons of Pure Calcium Carbonate Required to Produce an Increase of 1.0 pH Unit in the Reaction of Acre Six-Inch Layers of Soils with Various Clay and Organic Matter Contents[1]

Texture	% Clay	Organic Matter Content				
		Very Low (0.2 to 1%)	Low (1 to 2%)	Medium (2 to 4%)	High (4 to 8%)	Very High[2] (8 to 16%)
Sand	1	0.15-0.55	0.55-1.05	1.05-2.05	2.05-4.05	4.05-8.05
	2	0.20-0.60	0.60-1.10	1.10-2.10	2.10-4.10	4.10-8.10
	4	0.30-0.70	0.70-1.20	1.20-2.20	2.20-4.20	4.20-8.20
Loamy Sand	4	0.30-0.70	0.70-1.20	1.20-2.20	2.20-4.20	4.20-8.20
	6	0.40-0.80	0.80-1.30	1.30-2.30	2.30-4.30	4.30-8.30
	8	0.50-0.90	0.90-1.40	1.40-2.40	2.40-4.40	4.40-8.40
	10	0.60-1.00	1.00-1.50	1.50-2.50	2.50-4.50	4.50-8.50
Sandy Loam	8	0.50-0.90	0.90-1.40	1.40-2.40	2.40-4.40	4.40-8.40
	12	0.70-1.10	1.10-1.60	1.60-2.60	2.60-4.60	4.60-8.60
	16	0.90-1.30	1.30-1.80	1.80-2.80	2.80-4.80	4.80-8.80
	20	1.10-1.50	1.50-2.00	.2.00-3.00	3.00-5.00	5.00-9.00
Sandy Clay Loam	20	1.10-1.50	1.50-2.00	2.00-3.00	3.00-5.00	5.00-9.00
	25	1.35-1.75	1.75-2.25	2.25-3.25	3.25-5.25	5.25-9.25
	30	1.60-2.00	2.00-2.50	2.50-3.50	3.50-5.50	5.50-9.50
Clay Loam	25	1.35-1.75	1.75-2.25	2.25-3.25	3.25-5.25	5.25-9.25
	30	1.60-2.00	2.00-2.50	2.50-3.50	3.50-5.50	5.50-9.50
	35	1.85-2.25	2.25-2.75	2.75-3.75	3.75-5.75	5.75-9.75

B. Suitable pH Ranges and Minimum Calcium and Magnesium Levels for Different Field Crops on Mineral Soils[3]

	Suitable pH Ranges	Minimum Levels, Lbs./A.	
		CaO	MgO
Alfalfa and sweetclover	6.5 - 7.5	1200	150
Clovers	6.0 - 7.0	900	150
Miscellaneous legumes	5.5 - 6.5	600	150
Grasses	5.5 - 6.5	600	150
Cotton	5.5 - 6.5	600	150
Tobacco	5.4 - 5.8	300	150
Miscellaneous non-legumes	5.5 - 6.5	600	150

*For all footnotes, see following page.

TABLE 2—(Continued)

C. Choosing Kind of Limestone or Other Material for Different Field Crops on Basis of pH Values and Calcium and Magnesium Levels of Soil

pH Value	Calcium Level	Magnesium Level	Kind of Limestone or Other Material to Apply[4]
Below Middle of Range	Below Minimum	Below Minimum	Dolomitic Limestone
		Above Minimum	Calcic Limestone
	Above Minimum	Below Minimum	Dolomitic Limestone
		Above Minimum	Calcic or Dolomitic
In Upper Half of Range	Below Minimum	Below Minimum	Dolomitic Limestone
		Above Minimum	Calcic Limestone
	Above Minimum	Below Minimum	Dolomitic Limestone
		Above Minimum	None
Above Top of Range[5]	Below Minimum	Below Minimum	Gypsum and Soluble Magnesium
		Above Minimum	Gypsum
	Above Minimum	Below Minimum	Soluble Magnesium
		Above Minimum	None

[1]Sulfur may be used to lower pH values. In the absence of carbonates of calcium and magnesium, the quantities of sulfur required to produce a decrease of 1.0 pH unit are one-third of the quantities of calcium carbonate required to produce an increase of 1.0 pH unit.

[2]The requirements of mucky soils (16 to 35 percent organic matter) and of mucks and peats are higher than the maximums listed in this column. Five tons per acre should be the maximum for a single application of ground limestone to such soils, as well as to mineral soils for which higher amounts are indicated.

[3]For crops on organic soils, minimum pH values are lower, but minimum calcium and magnesium levels are higher.

[4]Use information in "A," preceding page, for estimation of quantities of limestone required for adjustment of pH values, and the following guide for determination of quantities of limestone or other material required for adjustment of calcium and magnesium levels:

Calcium: For each 300 pounds below minimum level, apply 1,200 pounds of calcic limestone, 2,400 pounds of dolomitic limestone, or 600 pounds of gypsum.

Magnesium: For each 75 pounds below minimum level, apply 1,000 pounds of dolomitic limestone or include 2% soluble magnesium in basic application of fertilizer. See Table 3.

[5]If lowering of pH seems desirable, apply sulfur. See footnote 1, above.

In order to secure maximum benefit, the indicated quantity of the proper kind of limestone or gypsum should be spread uniformly, preferably during seedbed preparation, and thoroughly incorporated with the surface soil to the maximum practical depth. The desired pH, calcium, and magnesium levels should be maintained by retreatment as often as necessary, usually every three to five years if limestone is used, or annually if gypsum or soluble magnesium is used.

during the fiscal year July 1, 1959 to June 30, 1960 than they did during the fiscal year 1954-1955. Similarly, they used 14.5 times as much limestone and 9.1 times as much supplemental nitrogen during 1959-1960 as they did during 1954-1955.

The basis for classification of soil-test results is presented in Table 1; the current recommendations for liming and fertilization on basis of soil-test results, for production of field crops, are outlined in Tables 2 and 3; and soil-test results on samples from field crop tracts in the general-farming area of northwestern and northeastern Florida, for the two-year period July 1, 1958 to June 30, 1960, are summarized in Tables 4 and 5. A summary of soil-test results on samples from pastures in counties outside the general-farming area, for the period July 1, 1959 to June 30, 1960, is given in Table 6.

Close examination of this information for indication of the kinds and amounts of limestone and fertilizer required for production of field crops in the different areas is suggested as a substitute for any remarks that might be offered as a summary of this report.

TABLE 3.—RECOMMENDATIONS FOR FERTILIZATION OF FLORIDA FIELD CROPS ON BASIS OF SOIL-TEST RESULTS.

A. Perennial Grasses on Mineral Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]			
		Basic[2]		Supplementary[3]	
P_2O_5	K_2O	Grade	Lbs./A.	Grade	Lbs./A.
Low	Low	8-8- 8*	750	20-0-10	300
	Med.	8-8- 8*	750	Nit.	60
	High	8-8- 4*	750	Nit.	60
Med.	Low	8-8- 8	750	20-0-10	300
	Med.	8-8- 8	750	Nit.	60
	High	8-8- 4	750	Nit.	60
High	Low	10-5-10	600	20-0-10	300
	Med.	10-5-10	600	Nit.	60
	High	10-5- 5	600	Nit.	60

[1]Other grades of mixed fertilizer of the same ratios may be substituted on the basis of equivalent quantities of nutrients.

Amounts recommended are for good moisture conditions. Reduce both the basic and the supplementary applications by 1/5 for fair, and by 2/5 for poor, moisture conditions.

[2]For established stands, the basic application, containing the proper quantities of any minor elements that are needed, should be broadcast at the beginning of the growing season.

For new plantings, the basic application recommended for annual grasses should be substituted and disked into the soil at or just before planting time.

[3]For established stands, the supplementary application should be broadcast during the middle, or not later than six weeks prior to the end, of the growing season. For new plantings, it should be broadcast as soon as the stand is well established, but not later than six weeks prior to the end of the growing season.

*In addition to the complete fertilizer, the basic application should include 500 pounds of 20 percent superphosphate or equivalent.

TABLE 3.—(Continued)

B. Annual Grasses on Mineral Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]			
		Basic[2]		Supplementary[3]	
P_2O_5	K_2O	Grade	Lbs./A.	Grade	Lbs./A.
Low	Low	4-12-12	600	Nit.	72
	Med.	4-12- 8	600	Nit.	72
	High	5-15- 5	480	Nit.	72
Med.	Low	5-10-15	480	Nit.	72
	Med.	5-10-10	480	Nit.	72
	High	6-12- 6	400	Nit.	72
High	Low	6- 6-18	400	Nit.	72
	Med.	6- 6-12	400	Nit.	72
	High	8- 8- 8	300	Nit.	72

[1]Other grades of the same ratios may be substituted on the basis of equivalent quantities of nutrients.

Amounts recommended are for good moisture conditions. Reduce both the basic and the supplementary applications by 1/5 for fair, and by 2/5 for poor, moisture conditions.

[2]The basic application, containing the proper quantities of any minor elements that are needed should be made at planting time. For row plantings, it should be placed in continuous bands 2 to 3 inches to either or both sides of the seed, and 2 to 3 inches below the level of the seed. For broadcast plantings, the fertilizer and the seed should be drilled simultaneously, or in separate operations, placing the fertilizer close to, but not in direct contact with, the seed.

[3]The supplementary fertilizer for corn and sorghum for grain or silage, and for pearlmillet for silage, should be applied 5 to 6 weeks after planting or when plants are approximately knee high. Pearlmillet for grazing or for green chopped forage should receive half the amount recommended, after each grazing or cutting. Oats, wheat, and rye grown for grain only, should receive half the amount recommended in late January or early February, and those grown for grazing or green chopped forage should receive half the amount recommended as soon as the stand is established, and the other half in late January or early February.

TABLE 3.—(Continued)

C. Cotton on Mineral Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]			
		Basic[2]		Supplementary[3]	
P_2O_5	K_2O	Grade	Lbs./A.	Grade	Lbs./A.
Low	Low	4-12-12	750	Nit.	60
	Med.	4-12- 8	750	Nit.	60
	High	5-15- 5	600	Nit.	60
Med.	Low	5-10-15	600	Nit.	60
	Med.	5-10-10	600	Nit.	60
	High	6-12- 6	500	Nit.	60
High	Low	6- 6-18	500	Nit.	60
	Med.	6- 6-12	500	Nit.	60
	High	8- 8- 8	375	Nit.	60

[1]Other grades of the same ratios may be substituted on the basis of similar quantities of nutrients.

Amounts recommended are for good moisture conditions. Reduce both the basic and the supplementary applications by 1/5 for fair, and by 2/5 for poor, moisture conditions.

[2]The basic application, containing the proper quantities of any minor elements that are needed should be made at planting, in bands three inches to each side of the seed row and 2 to 3 inches below the level of the seed.

[3]The supplementary fertilizer should be applied as a side-dressing when plants are 8 to 10 inches high.

TABLE 3.—(Continued)

D. Flue-Cured Tobacco on Mineral Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]			
		Basic[2]		Supplementary[3]	
P_2O_5	K_2O	Grade	Lbs./A.	Grade	Lbs./A.
Low	Low	3- 9- 9	1,000	3- 9- 9	1,000
	Med.	4-12- 8	750	3- 9- 9	1,000
	High	4-12- 8	750	4-12- 8	750
Med.	Low	3- 9- 9	1,000	4- 8-12	750
	Med.	3- 9- 9	1,000	4- 8- 8	750
	High	4-12- 8	750	4- 8- 8	750
High	Low	4- 8-12	750	4- 8-12	750
	Med.	4- 8- 8	750	4- 8-12	750
	High	4- 8- 8	750	4- 8- 8	750

[1]Amounts recommended are for good moisture conditions. Reduce both the basic and the supplementary applications by 1/5 for fair, and 2/5 for poor, moisture conditions.

Grades recommended as basic and supplementary applications should contain 2 percent soluble magnesium, not less than 25 percent of the nitrogen in nitrate form, and not more than 2 percent chlorine.

[2]The basic application should be made at planting time, in continuous bands 3 to 4 inches to each side of the plant row and 2 inches below the root crown of the transplant.

[3]The supplementary fertilizer should be applied as a side-dressing three weeks after transplanting or at first cultivation. If need for additional fertilizer is indicated by poor growth of plants following excessive rains, 100 to 200 pounds of 8-0-24* per acre may be applied not later than the beginning of the buttoning stage.

*With 50 percent or more of the nitrogen in nitrate form, and all of the potash derived from sulfate forms.

TABLE 3.—(Continued)

Clovers on Mineral Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]	
P_2O_5	K_2O	Grade	Lbs./A.
Low	Low	0-12-12	750
	Med.	0-15-10	600
	High	0-15- 5	600
Med.	Low	0-12-18	500
	Med.	0-12-12	500
	High	0-16- 8	375
High	Low	0- 8-24	375
	Med.	0-10-20	300
	High	0-12-12	250

[1]Other grades of the same ratios may be substituted on the basis of equivalent quantities of nutrients.

Amounts recommended are for good moisture conditions. Reduce by 1/5 for fair moisture conditions.

The fertilizer, containing the proper quantities of any minor elements that are needed, should be applied at planting time or at the beginning of the growing season.

Research results do not indicate that inclusion of nitrogen in fertilizers for clovers is a desirable practice. However, if some nitrogen is desired, 2-12-12, 2-12-8, 2-12-4, 2-8-12, 3-12-12, 3-12-6, 3-6-18, 4-8-16, and 5-10-10, respectively, or other grades of the same ratios, may be substituted at rates that will supply the desired quantities of phosphorus and potash.

On sandy soils, a supplemental application of 100 pounds of muriate of potash or 250 pounds of 0-8-24 in spring or early summer may be needed. If extra forage during late summer and early fall is needed, nitrogen, at rates up to 60 pounds per acre, may be applied to re-seeding clover-summer grass pastures two months after the clover stand has died down, but not later than early August.

TABLE 3.—(Continued)

F. Miscellaneous Legumes on Mineral Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]	
P_2O_5	K_2O	Grade	Lbs./A.
Low	Low	0-12-12	600
	Med.	0-15-10	480
	High	0-15- 5	480
Med.	Low	0-12-18	400
	Med.	0-12-12	400
	High	0-16- 8	300
High	Low	0- 8-24	300
	Med.	0-10-20	240
	High	0-12-12	200

[1]Other grades of the same ratios may be substituted on the basis of equivalent quantities of nutrients.

Amounts recommended are for good moisture conditions. Reduce by 1/5 for fair, and by 2/5 for poor, moisture conditions.

The fertilizer, containing the proper quantities of any minor elements that are needed, should be applied at planting time. For row plantings, it should be placed in continuous bands 2 to 2½ inches to each side of the seed and 2 inches below the seed level. For broadcast plantings, it should be applied with a grain drill, at a depth of 3 to 4 inches, prior to planting of the seed, which should be done in a separate operation.

Research results do not indicate that inclusion of nitrogen in fertilizers for legumes is a desirable practice. However, if some nitrogen is desired, 2-12-12, 2-12-8, 2-12-4, 2-8-12, 3-12-12, 3-12-6, 3-6-18, 4-8-16, and 5-10-10, respectively, or other grades of the same ratios, may be substituted at rates that will supply the desired quantities of phosphorus and potash.

TABLE 3.—(Continued)

G. All Field Crops on Organic Soils.

Soil-Test Results		Recommended Fertilizer Applications[1]	
P_2O_5	K_2O	Grade	Lbs./A.
Low	Low	0-12-12	750
	Med.	0-15-10	600
	High	0-15- 5	600
Med.	Low	0-12-18	500
	Med.	0-12-12	500
	High	0-16- 8	375
High	Low	0- 8-24	375
	Med.	0-10-20	300
	High	0-12-12	250

[1]Other grades of the same ratios may be substituted on the basis of equivalent quantities of nutrients.

The fertilizer, containing the proper quantities of any minor elements that are needed, should be applied at planting time. For perennial crops, the basic application should be broadcast at the beginning of the growing season. For annual crops, basic application should be broadcast and disked into soil at or just before planting time.

Research results do not indicate that inclusion of nitrogen in fertilizers for crops on organic soils is a desirable practice. However, if some nitrogen is desired, 2-12-12, 2-12-8, 2-12-4, 2-8-12, 3-12-12, 3-12-6, 3-6-18, 4-8-16, and 5-10-10, respectively, or other grades of the same ratios, may be substituted at rates that will supply the desired quantities of phosphorus and potash.

TABLE 4.—SUMMARY OF SOIL-TEST RESULTS ON SAMPLES FROM FIELD CROP TRACTS IN THE GENERAL-FARMING AREA OF NORTHWESTERN FLORIDA.*
July 1, 1958 to June 30, 1960

A. pH, Calcium and Magnesium.

pH Value	Calcium Level	Magnesium Level Low	Med.	High	Total
<5.5 (1,380)	Low	40.0	31.5	8.1	79.6
	Med.	3.0	6.1	8.5	17.6
	High	.4	.5	1.9	2.8
TOTAL		43.4	38.1	18.5	100.0
5.5-6.5 (2,746)	Low	21.2	13.0	2.7	36.9
	Med.	10.4	14.6	9.6	34.6
	High	4.4	10.4	13.7	28.5
TOTAL		36.0	38.0	26.0	100.0
>6.5 (137)	Low	.0	.7	.0	.7
	Med.	7.3	.7	6.6	14.6
	High	13.9	27.0	43.8	84.7
TOTAL		21.2	28.4	50.4	100.0
ALL (4,263)	Low	26.6	18.6	4.4	49.6
	Med.	7.9	11.4	9.2	28.5
	High	3.4	7.7	10.8	21.9
TOTAL		37.9	37.7	24.4	100.0

B. Phosphorus and Potash.

Phosphorus Level	Potash Level Low	Med.	High	Total
Low	11.3	23.7	8.9	43.9
Med.	5.1	16.8	8.8	30.7
High	3.2	11.2	11.0	25.4
TOTAL	19.6	51.7	28.7	100.0

*Figures in parentheses under pH Value indicate numbers of samples; others are percentages.

TABLE 5.—SUMMARY OF SOIL-TEST RESULTS ON SAMPLES FROM FIELD CROP TRACTS IN THE GENERAL-FARMING AREA OF NORTHEASTERN FLORIDA.*
July 1, 1958 to June 30, 1960

A. pH, Calcium and Magnesium.

pH Value	Calcium Level	Magnesium Level Low	Med.	High	Total
<5.5 (1,541)	Low	51.3	22.1	7.6	81.0
	Med.	3.3	4.5	4.7	12.5
	High	.6	1.2	4.7	6.5
TOTAL		55.2	27.8	17.0	100.0
5.5-6.5 (3,408)	Low	28.2	14.1	3.2	45.5
	Med.	9.3	12.8	8.3	30.4
	High	4.0	7.8	12.3	24.1
TOTAL		41.5	34.7	23.8	100.0
>6.5 (274)	Low	2.2	2.2	.0	4.4
	Med.	3.3	2.5	1.1	6.9
	High	20.4	26.3	42.0	88.7
TOTAL		25.9	31.0	43.1	100.0
ALL (5,223)	Low	33.7	15.8	4.3	53.8
	High	3.9	6.8	11.6	22.3
	High	3.9	6.9	11.6	22.3
TOTAL		44.8	32.4	22.8	100.0

B. Phosphorus and Potash.

Phosphorus Level	Potash Level Low	Med.	High	Total
Low	8.4	3.2	.6	12.2
Med.	15.4	6.4	.9	22.7
High	29.9	24.7	10.5	65.1
TOTAL	53.7	34.3	12.0	100.0

*Figures in parentheses under pH Value indicate numbers of samples; others are percentages.

TABLE 6.—SUMMARY OF SOIL-TEST RESULTS ON SAMPLES FROM PASTURES IN COUNTIES OUTSIDE THE GENERAL-FARMING AREA OF NORTHWESTERN AND NORTHEASTERN FLORIDA.*
July 1, 1959 to June 30, 1960

A. pH, Calcium and Magnesium.

pH Value	Calcium Level	Magnesium Level			Total
		Low	Med.	High	
<5.5 (488)	Low	17.4	6.8	4.9	29.1
	Med.	4.7	9.2	12.7	26.6
	High	2.9	11.3	30.1	44.3
TOTAL		25.0	27.3	47.7	100.0
5.5-6.5 (827)	Low	12.7	2.7	.2	15.6
	Med.	8.1	5.1	5.2	18.4
	High	9.2	18.6	38.2	66.0
TOTAL		30.0	26.4	43.6	100.0
>6.5 (186)	Low	.5	.0	.0	.5
	Med.	3.2	1.6	.0	4.8
	High	6.5	21.5	66.7	94.7
TOTAL		10.2	23.1	66.7	100.0
ALL (1,501)	Low	12.7	3.7	1.7	18.1
	Med.	6.4	6.0	7.0	19.4
	High	6.8	16.6	39.1	62.5
TOTAL		25.9	26.3	47.8	100.0

B. Phosphorus and Potash.

Phosphorus Level	Potash Level			Total
	Low	Med.	High	
Low	16.7	6.3	2.7	25.7
Med.	15.2	7.7	2.5	25.4
High	18.5	18.5	11.9	48.9
TOTAL	50.4	32.5	17.1	100.0

*Figures in parentheses under pH Value indicate numbers of samples; others are percentages.

Relationship of Soil Nitrogen to Crop Response from Fertilizer Nitrogen Applied to Mineral Soils[1]

W. L. PRITCHETT, M. N. MALIK AND C. F. ENO[2]

Soil testing procedures have been developed and successfully used for determining the amount of extractable phosphorus and potassium in soils in almost all of the states. Tests for these two primary nutrients have been used in some soil testing programs for over 50 years. However, it has been only in the last decade that attention has been directed toward developing a reliable method of routinely testing for soil nitrogen as a basis for predicting nitrogen fertilizer needs. Although nitrogen fertilizers account for the greatest part of the farmers' fertilizer bill, interest in a soil test for predicting the need for this nutrient has developed slowly due to the difficulty of measuring the rate at which soil nitrogen becomes available. Furthermore, many mineral soils, such as those found in Florida, supply a relatively small percentage of the total crop requirement for this nutrient.

Several methods of testing for soil nitrogen are now being used, or being investigated. A qualitative test for nitrate nitrogen is used in many states as a rapid means of determining the soil nitrogen supply. This method is subject to many variables and does not give a satisfactory measure of the nitrogen-supplying potential of soils. More quantitative procedures involve tests for nitrate production during a two-week incubation period in the laboratory (4, 8), or the determination of total nitrogen (2) or organic matter (7). Correlations of test results with crop yields have been worked out in the states in which these tests are being used. They are reported to give reliable estimates of the amount of nitrogen supplied by the soil (3, 4, 5, 7).

Pritchett, *et al.* (6) reported that although nitrate production during two weeks of soil incubation might be expected to be more closely related to crop yields than values obtained by total soil nitrogen or organic matter tests, either of the first two methods could be used for estimating the nitrogen-supplying power of mineral soils of Florida. Neither method, however, had been evaluated in the field or greenhouse. This report deals with the relationship of crop response obtained in the greenhouse from nitrogen fertilization to (a) nitrate production and (b) total soil nitrogen.

METHODS OF PROCEDURE

Greenhouse experiments were conducted on 12 mineral soils, representing some of the principal agricultural soils of Florida (Table 1). All soils were collected from cultivated fields, air-dried, sieved and placed in 2-gallon pots. The equivalent of 200 pounds per acre of P_2O_5 and K_2O as superphosphate and potassium chloride, respectively, were applied to all soils. The equivalent of one ton of calcium hydroxide per acre was

[1]Florida Agricultural Experiment Stations Journal Series, No. 1190.

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applied to all soils, except soils No. 1, 2 and 3 where the soil pH was 5.6 or above. Nitrogen, as ammonium nitrate, was applied at rates equivalent to 0, 20, 40, 80 and 160 pounds per acre, calculated on the assumption that the soils weighed 2,000,000 per acre six inches. There were three replications of each soil type.

Floriland oats was planted in October and harvested in February and April. Following the second harvest of oats, the top 6 inches of soil in each pot was stirred and then refertilized with the same amounts of phosphorus, potassium and nitrogen as previously applied. Cattail millet was planted as the summer crop and harvested twice. The plant materials were oven-dried, and analyzed for total nitrogen by the Kjeldahl procedure.

Soil samples, taken from each soil type before potting, were analyzed for pH and ammonium acetate (pH 4.8) extractable nutrients. They were also analyzed for total nitrogen by the Kjeldahl-Gunning procedure (1); organic matter by the Walkley-Black method (9) and nitrate production during 2 weeks of incubation according to the Iowa procedure (8), as modified by Malik (5).

RESULTS AND DISCUSSION

Soil and Plant Data: The pH, extractable nutrients, organic matter, total nitrogen and nitrate production are given in Table 1. Organic matter content of the soils ranged from a low of 0.91 percent in the Lakeland sand to a high of 2.91 percent in the Red Bay fine sandy loam. In general, the fine textured soils contained larger amounts of organic matter than the coarse sands. Total nitrogen content generally varied directly with organic matter content and ranged from 0.021 up to 0.066 percent. Nitrate production varied from 4.7 ppm. in Leon sand to 19.9 ppm. in Magnolia fine sandy loam.

Yields and nitrogen content of the four forage harvests were used to calculate percentage nitrogen recovery data. Recovery was calculated by subtracting the uptake of nitrogen in the check plots from that taken up in plots receiving a particular rate of nitrogen.

TABLE 1.—THE PH, AVAILABLE NUTRIENTS,* TOTAL NITROGEN AND ORGANIC MATTER CONTENT AND NITRATE PRODUCTION IN SOIL SAMPLES.

No.	Soil Type	pH	Available nutrients lbs. per acre CaO	MgO	P_2O_5	K_2O	Total nitrogen (percent)	Organic matter (percent)	NO_3-N produced (ppm.)
1.	Gainesville lfs	5.6	977	251	34	127	0.050	1.75	12.2
2.	Hernando lfs	5.8	88	197	45	124	0.048	1.79	10.3
3.	Scranton fs	5.1	126	67	28	91	0.066	2.38	16.2
4.	Leon fs	5.1	574	50	19	15	0.022	1.17	4.7
5.	Magnolia fsl	5.1	350	135	62	443	0.055	1.40	13.2
6.	Magnolia fsl	5.1	574	150	40	311	0.066	1.79	19.9
7.	Tifton ls	5.2	260	135	4	34	0.050	1.98	11.5
8.	Lakeland ls	5.3	171	33	14	46	0.029	1.38	7.7
9.	Lakeland fs	5.8	932	31	12	35	0.021	0.91	6.1
10.	Blanton lfs	4.8	224	31	67	146	0.045	2.00	9.7
11.	Red Bay fsl	5.2	562	166	3	133	0.070	2.91	19.6
12.	Ruston fsl	4.9	145	31	9	35	0.032	1.05	6.2

*Ammonium acetate (pH 4.8) extractable

The yield of oats on unfertilized soils varied from an average of 1,176 to 5,953 pounds per acre, while the yield of unfertilized millet ranged from 1,764 to 4,424 pounds per acre. Both oat and millet yields increased with each increase in the rate of nitrogen fertilization on all soils but response varied among soils. The average yields at each rate of nitrogen fertilization for all soils are shown in Figure 1.

The nitrogen uptake increased linearly with increases in yield of forage, but tended to be higher in fine textured soils. Correlation coefficients of 0.99 and 0.97 for oats and millet, respectively, were highly significant. Recovery of nitrogen applied to oats was higher than from millet. For oats, the average recoveries of nitrogen were 48.9, 56.7, 55.9 and 54.5 percent, at rates of nitrogen equivalent to 20, 40, 80 and 160 pounds per acre, respectively. Millet recovered 26.7, 32.8, 45.9 and 50.8 percent, respectively, for the above rates of applied nitrogen. Millet recovered a significantly smaller percentage of the nitrogen at lower rates of application than at

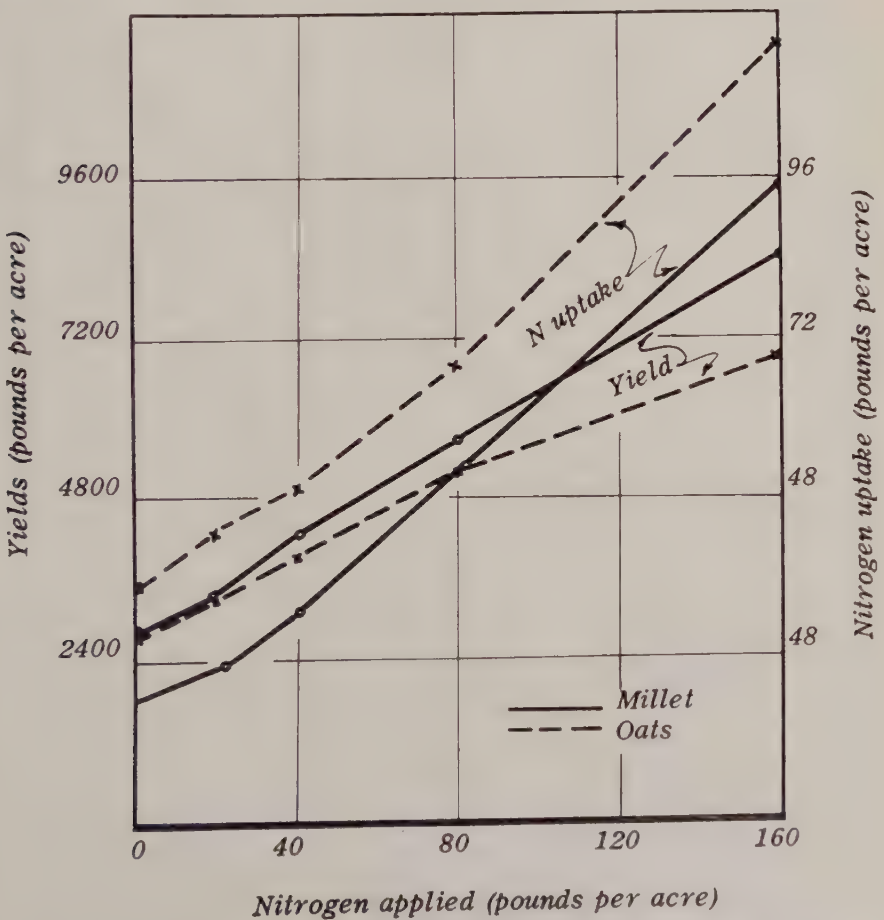

Fig. 1.—The Average Yield and Nitrogen Uptake by Oats and Millet Fertilized with Various Rates of Nitrogen.

higher rates. This was probably due to immobilization during decomposition of root residues.

One way to interpret soil test results in terms of fertilizer needs is to correlate the soil analytical data with yield response obtained from applications of fertilizer. Regression equations were developed for the relationships of yield response to total soil nitrogen and nitrate production. Organic matter content of soil samples was determined (Table 1), however, the relationship of this soil property to crop yield response was not as close as that for total soil nitrogen or nitrate production. For this reason, results of organic matter tests are not included in the following discussion.

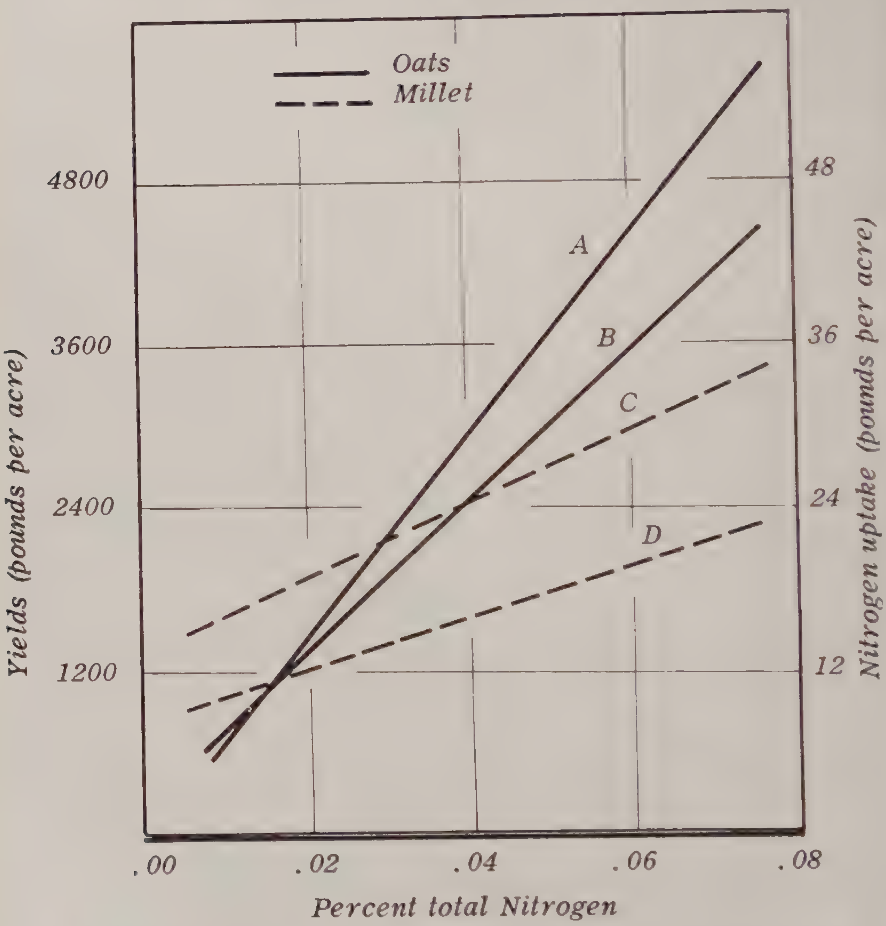

Fig. 2. The Relationship of Total Soil Nitrogen to Yield and Nitrogen Uptake by Oats and Millet on Unfertilized Soils.

Regression Equations and Correlation Coefficients

A.	Oat, Yields	(Y) =	0.840 + 232.322X	r = 0.706**
B.	Oat, N. Uptake	(U) =	—0.004 + 3.195X	r = 0.693**
C.	Millet, Yields	(Y) =	5.504 + 119.869X	r = 0.680**
D.	Millet, N Uptake	(U) =	0.035 + 0.837X	r = 0.652**

Total Soil Nitrogen and Crop Response: The relationship of total soil nitrogen to yield of oats and millet in the check (no nitrogen added) pots is expressed by regression equations and plotted in Figure 2. The correlation coefficients (r) of 0.706 and 0.680 for oat and millet crops, respectively, were both highly significant. Practically speaking, each 0.01 percent of total nitrogen in the soil resulted in approximately 540 pounds per acre of forage. Nitrogen uptake from soils receiving no nitrogen fertilizer was also linear and closely related to the total nitrogen content of the soils (Figure 2). The correlation coefficients of 0.693 and 0.652 for oats and millet, respectively, were highly significant. Each 0.01 percent nitrogen in the soil resulted in the uptake of 7.5 pounds of nitrogen per acre in the oat forage. For example, an oat crop would have utilized 3.75 percent of the

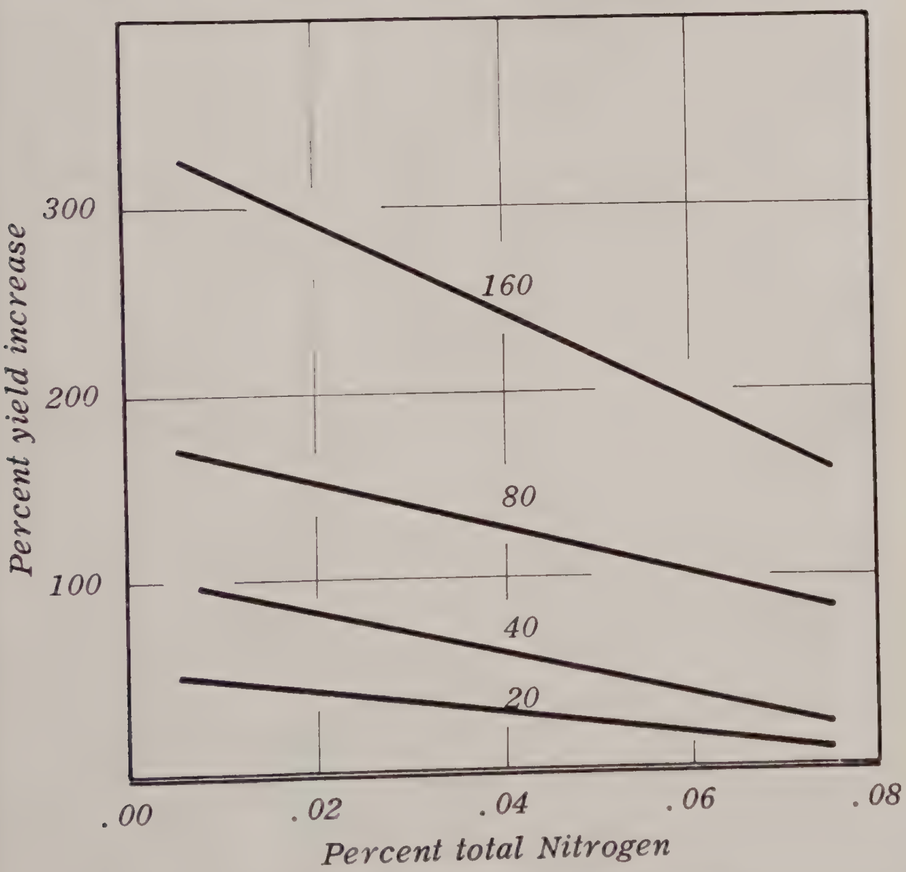

Fig. 3.—The Relationship of Total Nitrogen to the Percent Increase in Yield of Oats Obtained from Various Rates of Fertilizer Nitrogen.

Regression Equations and Correlation Coefficients

20 lbs. of N per acre:	(Y) = 51.24 — 548.61X	r = —0.513
40 lbs. of N per acre:	(Y) = 106.93 — 1030.98X	r = —0.426
80 lbs. of N per acre:	(Y) = 177.23 — 1139.81X	r = —0.613*
160 lbs. of N per acre:	(Y) = 339.36 — 2372.21X	r = —0.666*

total nitrogen in a soil which contained 200 pounds per acre. For oats, the average percentage yield increase over that of the unfertilized soils was 25.9, 59.3, 109.8 and 190.8 for nitrogen rates equivalent to 20, 40, 80 and 160 pounds per acre, respectively (Figure 3). The yield increase of millet was similar to that obtained for oats (Figure 4). The percent response was highest in soils of low nitrogen content. For example, the percent response was generally 5 to 10 percent higher for sands than for loams. This is a reflection of the tendency of plants to absorb a nutrient from different sourcs in proportion to the amounts of the nutrient from those sources available in the soil.

Responses to 20 and 40 pounds of nitrogen per acre were not significant. Although responses to these low rates of application increased as the nitro-

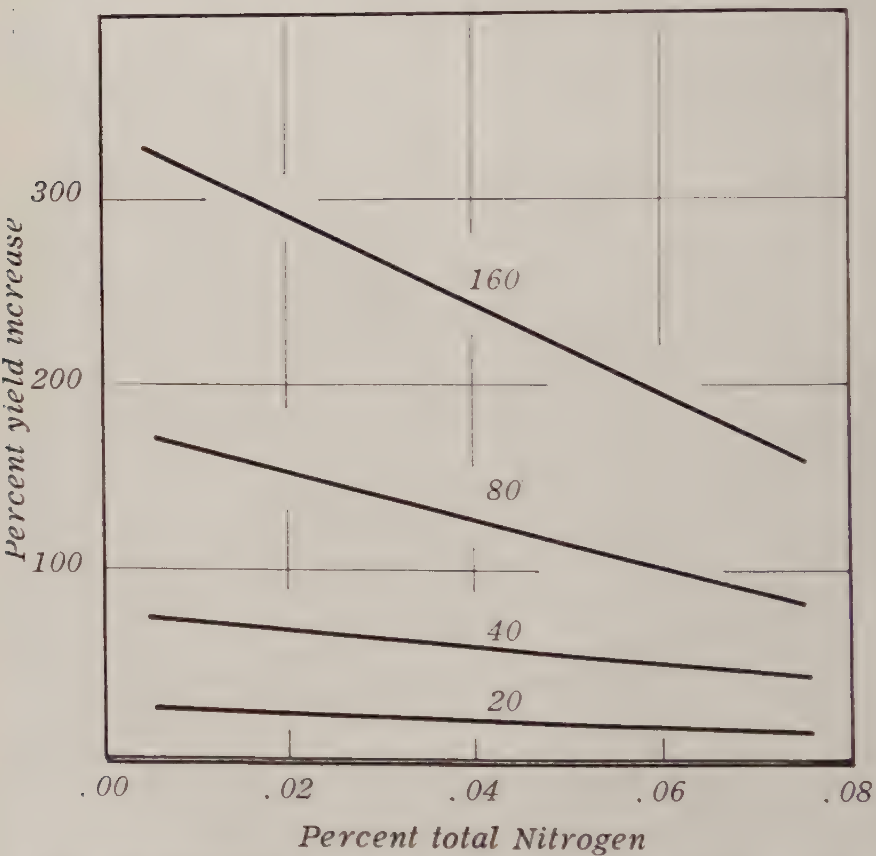

Fig. 4.—The Relationship of Total Soil Nitrogen to the Percent Increase in Yield of Millet Obtained from Various Rates of Fertilizer Nitrogen.

Regression Equation and Correlation Coefficients

20 lbs. of N per acre:	(Y) = 28.86 — 97.40X	r = —0.404
40 lbs. of N per acre:	(Y) = 76.88 — 389.56X	r = —0.322
80 lbs. of N per acre:	(Y) = 177.23 — 1139.81X	r = —0.543*
160 lbs. of N per acre:	(Y) = 339.36 — 2372.21X	r = —0.672*

gen content of soils decreased, the responses were not consistent enough to make the relationship significant. The relationships of total soil nitrogen to percentage yield increase from 80 and 160 pounds of nitrogen were significant at the 5 percent level of probability for both oats and millet. These correlation coefficients indicate that results of a test for total soil nitrogen can be used more reliably to predict responses from medium to high rates of nitrogen than to low rates.

Nitrate Production and Crop Response: Nitrate production was found to have a highly significant positive linear relationship with oat and millet

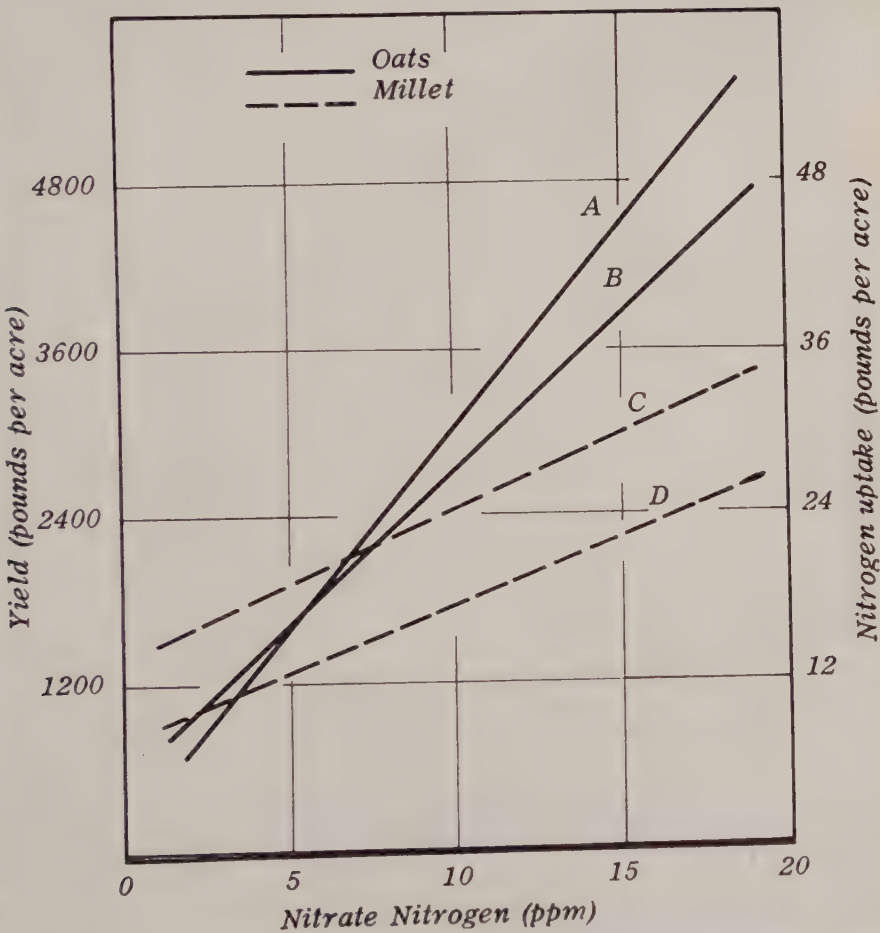

Fig. 5.—The Relationship of Nitrate Production in Soils During Incubation to Yield and Nitrogen Uptake by Oats and Millet on Unfertilized Soils.

Regression Equation and Correlation Coefficients

A.	Oat, Yields	(Y) =	2.116 + 0.826X	r = 0.756**
B.	Oat, N Uptake	(U) =	0.007 + 0.012X	r = 0.778**
C.	Millet, Yields	(Y) =	5.832 + 0.445X	r = 0.772**
D.	Millet, N Uptake	(U) =	0.038 + 0.003X	r = 0.740**

yields on the unfertilized soils; the correlation coefficients were 0.756 and 0.772 for oats and millet, respectively. The regression equations are shown in Figure 5. The oat forage yield increased approximately 740 pounds per acre for each 3 ppm. of nitrate nitrogen in the soils. The absorption of nitrogen by the oat and millet crops was also highly significantly correlated with nitrate-nitrogen. Correlations between nitrate production and yield and nitrogen uptake were higher than those between total soil nitrogen and yield and nitrogen uptake.

The percentage increases in yield of oat forage from 20, 40, 80 and 160 pounds of nitrogen per acre relative to nitrification rates are shown in Figure 6. This same relationship for millet is shown in Figure 7. The correlation coefficients were significant at the 5 percent level of probability

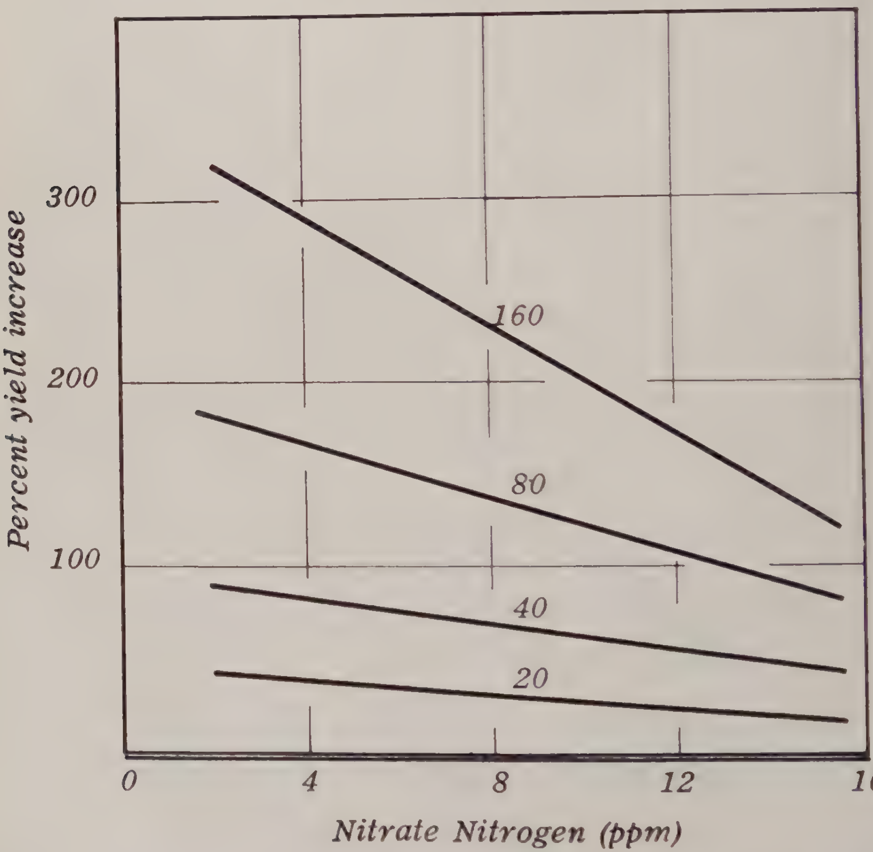

Fig. 6.—The Relationship of Nitrate Production in Soils During Incubation to the Percent Increase in Yield of Oats Obtained from Various Rates of Fertilizer Nitrogen.

Regression Equation and Correlation Coefficients

20 lbs. of N per acre:	(Y) =	43.88 — 1.571X	r = —0.424*
40 lbs. of N per acre:	(Y) =	96.42 — 3.242X	r = —0.400
80 lbs. of N per acre:	(Y) =	197.30 — 7.639X	r = —0.593*
160 lbs. of N per acre:	(Y) =	343.60 — 13.350X	r = —0.656*

for the 80- and 160-pound applications for both crops. However, of the lower rates only the 20 pound application to millet was significant.

The regression equations, describing the relationship between nitrate production and percent yield increase for a given increment of fertilizer nitrogen, can be a useful tool for predicting crop response. For example, given the rate of nitrification in a soil, the yield of oats, without the addition of nitrogen fertilizers, can be predicted with a regression equation such as given in Figure 5. This assumes that phosphorus, potassium and other environmental factors do not limit yields. The percentage yield increase, over this check yield, can be estimated for the several rates of fertilizer nitrogen from the regression lines in Figure 6. For instance, the response to 20, 40, 80 and 160 pounds of nitrogen per acre, when the soil test showed an equivalent of 8 ppm. of nitrate nitrogen during two weeks of

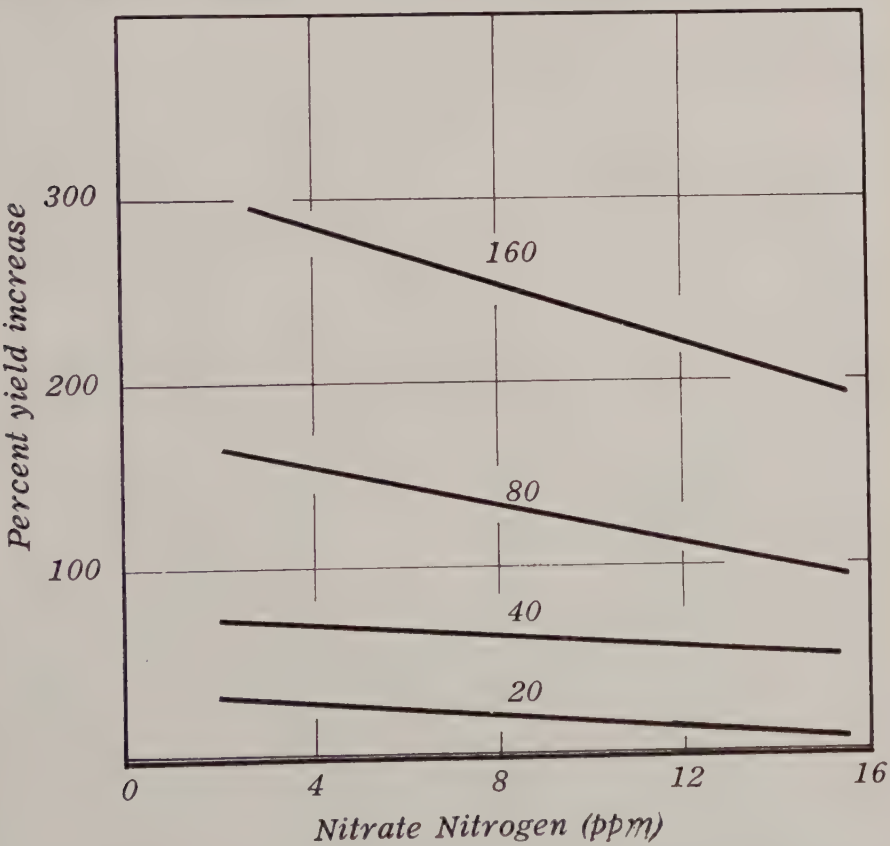

Fig. 7.—The Relationship of Nitrate Production in Soils During Incubation to the Percent Increase in Yield of Millet Obtained from Various Rates of Fertilizer Nitrogen.

Regression Equation and Correlation Coefficients

20 lbs. of N per acre:	(Y) =	30.45 — 0.532X	r = —0.665*
40 lbs. of N per acre:	(Y) =	76.31 — 1.552X	r = —0.372
80 lbs. of N per acre:	(Y) =	174.36 — 4.348X	r = —0.623*
160 lbs. of N per acre:	(Y) =	316.60 — 7.583X	r = —0.647*

incubation, would be 31, 70, 136 and 237 percent increase, respectively, over the check yield.

In order to interpret results of soil nitrogen tests in terms of fertilizer nitrogen applications for a given crop, the tests need to be calibrated with results from field experiments involving rates of nitrogen applied to the crop.

SUMMARY AND CONCLUSIONS

Soils representing 12 of the principal agricultural soil types in Florida were collected from cultivated fields. Oats and then millet were grown in the greenhouse in pots containing each soil. These soils were fertilized at rates equivalent to 0, 20, 40, 80 and 160 pounds of nitrogen per acre. Forage yields and nitrogen uptake were determined on two harvests for each crop. Samples were collected from each soil type before fertilization and analyzed for organic matter, total nitrogen and nitrate production during two weeks of incubation. Statistical studies were made of the relationships of soil nitrogen to crop yields and responses to fertilizer nitrogen in order to evaluate the usefulness of soil tests as a basis for predicting the need for nitrogen fertilizer.

Organic matter was not significantly related to forage yield or nitrogen uptake and was omitted from the discussion.

Total soil nitrogen and nitrate production were significantly related to forage yields and nitrogen uptake by both oats and millet in unfertilized soils. The correlation coefficient values were highest for nitrate nitrogen.

The regression of total soil nitrogen and nitrate nitrogen on percent yield increases of oats and millet became more highly significant with increases in the rate of fertilization. Correlation coefficients for these relationships were not significant at the low rate of application but were significant at the higher rates. Response was more closely correlated with nitrate production than with total soil nitrogen.

Although Florida's mineral soils are rather low in organic matter and total nitrogen, plant uptake indicated that they generally supply 20 to 40 pounds of available nitrogen during a growing season. Quantitative tests for soil nitrogen are laborious and time consuming as presently conducted, but there are indications that they can be simplified for use in a service program.[3] Furthermore, soil nitrogen levels do not change rapidly in soils, so that a test for this nutrient could serve as a basis for nitrogen recommendations for a number of years—unless a drastic change in the cropping system was introduced. The relationships of the results of the two soil tests to crop response were not significantly different. However, under the conditions of the tests, nitrate production was more closely correlated to yield and response than total nitrogen. Either of the tests could be used in a soil testing program provided they have been adequately calibrated in field experiments. A total nitrogen test probably could be more easily adapted for use in a service laboratory than could the more time consuming incubation method.

[3]Moskovic, Armin. A rapid method for the determination of nitrogen in soils. Soils Department Mimeo. Report 60-2. October, 1959.

LITERATURE CITED

1. Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. Washington, D. C. Ed. 8. 1955.
2. Altoe, O. J., T. A. Richard, S. Moskal, and E. Truog. A chemical method of determination of available soil nitrogen. 7th Cong. Int. Soc. of Soil Sci. 1960 (in press).
3. Cook, F. D., F. G. Warder and J. L. Doughty. Relationship of nitrate accumulation to yield response of wheat in some Saskatchewan soils. Canad. Jour. Soil Sci. 37:84-88. 1957.
4. Fitts, J. W., W. V. Bartholomew and H. Heidel. Correlation between nitrifiable nitrogen and yield response of corn to nitrogen fertilizer on Iowa soils. Soil Sci. Soc. Amer. Proc. 17:119-122. 1953.
5. Malik, M. N. An evaluation of several methods of determining the nitrogen status of Florida soils. M. S. Thesis, Univ. of Fla., Gainesville, Fla. 1958.
6. Pritchett, W. L., C. F. Eno and M. N. Malik. The nitrogen status of the mineral soils of Florida. Soil Sci. Soc. Amer. Proc. 23:172-130. 1959.
7. Smith, G. E. Soil fertility and corn production. Mo. Agr. Exp. Sta. Bul. 583. 1952.
8. Stanford, G. and J. Hanway. Predicting nitrogen fertilizer needs of Iowa soils: II. A simplified technique for determining relative nitrate production in soils. Soil Sci. Soc. Amer. Proc. 19:74-77. 1955.
9. Walkley, A. An examination of methods for determining organic carbon and nitrogen in soils. Jour. Agr. Sci. 25:598-609. 1935.

A Study of the Reproducibility of Soil Analysis Results[1]

HERMAN L. BRELAND and JAMES NESMITH[2]

INTRODUCTION

The general impression many people have of soil analysis is that it can be easily and quickly carried out in a laboratory. The belief is also widespread that the data obtained by any of the methods of soil analysis is absolute. With this information all the grower has to do is add the needed fertilizer and gather an abundant harvest. However, there are many factors that must be considered if maximum benefits are to be obtained from soil analysis.

Fitts and Nelson (2) pointed out that there were four major phases of soil testing: calibration of the test with crop response, securing of representative soil samples, chemical testing procedure and making the recommendations. This study deals with one phase of the problem, the chemical testing procedures. It is the authors' belief that, in general, five determinations should be made on each soil sample. They are pH, calcium, magnesium, phosphorus and potassium. Total soluble salts and copper should be determined also when needed or upon request.

It must be recognized that no one method is infallible and that the value obtained is, at best, empirical. One of the criticisms of the soil analysis program has been that the values obtained are not absolute. However, there are many factors such as temperature, humidity, contamination, etc., that may cause soil test values to vary.

A 0.002 *N* sulfuric acid extraction solution introduced by Truog (5) for phosphorus, has been used by some laboratories in the past. Sodium

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acetate, pH 4.8, extracting solution introduced by Morgan (3) has been the most popular. It is being used by several laboratories in the state. Other laboratories have changed to ammonium acetate, pH 4.8, as an extractant with the advent of the flame photometer. The Soil Testing Laboratory at the University of Florida is presently using the latter extractant.

The objective of this study was to determine the error associated with the analytical methods of soil analysis used by the Soil Testing Laboratory. Eighteen bulk soil samples were repeatedly subsampled and analyzed in the laboratory. A total of twenty subsamples were analyzed on different days over a time interval of about four months. Duplicate determinations were made on each subsample analyzed.

MATERIALS AND METHODS

Soil analysis cannot give an accurate estimation of the nutrient content of a soil area unless the sample itself is an accurate representation of that soil. Therefore, an attempt was made to obtain representative samples in each case.

Soil Samples—Surface (0"-6") soil samples were obtained from different areas of the state (Table 1). They represented five of the major mineral soil types (two were Lakeland fine sands) of the state. In order to show the variation that may occur in soil analysis data for different samples from the same soil type, three samples of each soil type were collected. The three samples represented the virgin, young cultivated or pasture and old cultivated soil. Approximately 100 pounds of soil were obtained for each of the 18 samples. The samples were spread and allowed to air-dry in the greenhouse. Each sample was sieved, mixed thoroughly and stored in covered plastic containers.

A soil sampling tube was used for obtaining sub-samples from each container. The determinations were made on five consecutive days of four separate weeks covering a period of about four months. The five sub-

TABLE 1.—SOIL SAMPLES

Soil No.	Soil Type
1.	Ruston fsl—Virgin—Santa Rosa County
2.	Ruston fsl—Pasture (young cultivated)—Santa Rosa County
3.	Ruston fsl—Old cultivated—Santa Rosa County
4.	Tifton fsl—Virgin—Gadsden County
5.	Tifton fsl—Pasture (young cultivated)—Gadsden County
6.	Tifton fsl—Old cultivated—Gadsden County
7.	Lakeland fs—Virgin—Suwannee County
8.	Lakeland fs—Pasture (young cultivated)—Suwannee County
9.	Lakeland fs—Old cultivated—Suwannee County
10.	Leon fs—Virgin—Alachua County
11.	Leon fs—Pasture (young cultivated)—Alachua County
12.	Leon fs—Old cultivated—Alachua County
13.	Lakeland fs—Virgin—Marion County
14.	Lakeland fs—Young cultivated—Marion County
15.	Lakeland fs—Old cultivated—Marion County
16.	Blanton fs—Virgin—Polk County
17.	Blanton fs—Young cultivated—Polk County
18.	Blanton fs—Old cultivated—Polk County

samples, for each of the four weeks, were taken at the beginning of the week they were to be analyzed. A different subsample was taken for each of the twenty analyses.

Methods of Analysis—Methods of analysis were the same as those employed in the Soil Testing Laboratory (1). Soil reaction (pH) was determined with a potentiometer and glass electrode. One part soil and two parts water were mixed and allowed to stand at least one hour before making the pH determination. All other determinations were made on a single leachate obtained by shaking 5.00 gm. of soil and 25 ml. of NH_4OAc, pH 4.8, for 30 minutes and filtering. A survey made in 1958 by the senior author showed that most soil testing laboratories in the southeast were using a similar soil:extractant ratio (4).

Calcium and potassium determinations were made with a Beckman Model B spectrophotometer with flame attachment and oxygen-acetylene fuel. Magnesium was determined with a Beckman Model DU spectrophotometer having a photomultiplier, flame attachment and oxygen-hydrogen fuel. The phosphorus determination was made with acid ammonium molybdate and stannous chloride; the intensity of the blue color which developed was read on a photoelectric colorimeter.

The pH determinations were re-run in each case, usually by a different operator, to give duplicate sample readings for each day. Calcium, magnesium, potassium and phosphorus determinations also were made in duplicate for each extract.

RESULTS AND DISCUSSION

The analytical data given in Tables 2-7 were obtained the first week. The values obtained for each determination are given for each day of the week. They are presented as being representative of the data obtained for the other three weeks.

The maximum variation of the average daily pH values from the mean was 0.2 unit. This variation was found on five soil samples. The soils were Tifton (Nos. 4 and 5), Leon (No. 10) and Lakeland (Nos. 13 and 15). However, this magnitude of variation occurred only once during the week for four of the five samples. A 0.3 of a pH unit variation was obtained between the average of duplicate determinations for the five days in one instance for the Lakeland soil (No. 13). A variation of 0.2 of a pH unit was obtained for the Tifton (Nos. 4 and 5) and Blanton (No. 16) soils.

The average daily calcium values varied from the mean for the week by over 100 pounds of CaO per acre for only three soils. They were Tifton (Nos. 5 and 6) and Leon (No. 12). The variations from the means were 42, 13 and 8 percent, respectively. In only a few instances did the variation exceed 10 percent. In no case was there a variation of more than 13 pounds of CaO per acre between the average of the duplicate determinations for the five days and the overall mean.

The largest numerical variation from the overall mean obtained for magnesium was 48 pounds of MgO per acre for the Lakeland soil (No. 15). This amounted to only an 8% variation for days. However, there were other determinations with a larger percentage variation from the mean of the week. The largest was approximately 55% for the Lakeland soil (No. 13). The largest variation from the mean obtained for duplicates for the week was 8 pounds of MgO per acre.

The large percentage variation, or error, for soil number 13 was obtained from the extreme lower end of the magnesium curve. The average of all determinations for the week for that soil was only 22 pounds of MgO per acre and the maximum variation from the mean was 12 pounds per acre. It is difficult to make a more accurate determination at this low concentration. The 12 pounds of MgO per acre represents a 1.5% transmittance variation for the instrument. The concentration of magnesium in the sample at the time of determination was a little less than 7 pounds of MgO per acre since the soil:extractant ratio was 1 to 5.

The maximum variation of average daily phosphorus values from the mean was 40% for one sample (No. 3). This represented an actual variation of 2 pounds P_2O_5 from the mean of 5 pounds per acre. Most of the other variations were much less when expressed as percentages. The largest numerical variation was 9 pounds from a mean of 80 pounds of P_2O_5 per acre or about 11%.

The maximum daily variation of potassium from the mean was 37 pounds of K_2O per acre, or 12%. This was for the Tifton soil (No. 6). Most other variations were 15% or less. The variation of duplicate determinations was negligible. It amounted to only 2 pounds of K_2O per acre in two instances for a maximum variation of less than 2%.

The average pH, calcium, magnesium, phosphorus and potassium values obtained for each week are given in Tables 8 through 12.

The average variation in pH values among weeks was 0.1 of a pH unit, or less, in all cases except for the virgin Lakeland soil (No. 13) which was 0.2 (Table 8). The largest variation obtained for calcium was 115 pounds per acre of CaO for the old cultivated Lakeland soil (No. 15). This was about a 5% variation from the mean for that soil (Table 9). The largest percentage variation was about 43% or 29 pounds per acre from the weekly mean of 67 pounds of CaO per acre for the virgin Lakeland soil (No. 13). The largest numerical and percentage variations obtained for magnesium were 34 pounds of MgO per acre and 49% respectively (Table 10). These values were equivalent to a mean variation of 16% and 15 pounds of MgO per acre, for the Blanton and Lakeland soils (Nos. 18 and 9). The largest mean variation for phosphorus (Table 11) was 8 pounds of P_2O_5 per acre, or 8%, for the Blanton soil (No. 18). A variation of 33% in the phosphorus values was obtained in two instances. However, this represented only a one pound variation from the mean of 3 pounds of P_2O_5 per acre. A potassium variation of as much as 11 pounds of K_2O per acre was obtained on the virgin Ruston (No. 1) and Tifton (No. 5) soils (Table 12). This represented an 8 and 3% variation from the mean for the potassium determinations.

Variations in soil analytical data for any one soil type may be larger than the variations between soil types. This is shown by the Lakeland samples (Nos. 7-9 and 13-15), in Table 13. Analysis of the virgin samples (Nos. 7 and 13) showed them to be similar, but the data were very different for the old cultivated soils (Nos. 9 and 15). The differences noted for the Lakeland soils appear to be greater than the differences within samples of the other soil types. The results given in Table 14 point out the fallacy of pooling data for a particular soil type without regard to past history. Each value represents an average of data obtained by days for the four weeks on the 3 soils representing time, in regard to cultivation, for the 6 different soil types. It can readily be seen that many of the varia-

TABLE 2.—THE pH AND EASILY EXTRACTABLE NUTRIENT LEVELS OBTAINED ON 5 CONSECUTIVE DAYS FOR A RUSTON FINE SANDY LOAM SOIL.*

	pH			CaO lbs/A			MgO lbs/A			P_2O_5 lbs/A			K_2O lbs/A		
	Duplicates			Duplicates			Duplicates			Duplicates			Duplicates		
Days	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.
No 1—Virgin soil															
1	5.4	5.5	5.5	245	245	245	153	153	153	2	3	3	120	126	123
2	5.4	5.5	5.5	252	252	252	114	166	140	1	2	2	114	114	114
3	5.4	5.5	5.5	227	227	227	166	127	147	4	2	3	126	126	126
4	5.4	5.4	5.4	266	266	266	182	166	174	3	3	3	126	126	126
5	5.5	5.2	5.3	266	227	247	91	114	103	3	3	3	120	132	126
Ave.	5.4	5.4	5.4	251	243	247	141	145	143	3	3	3	121	125	123
No. 2—Young Cultivated or Pasture soil															
1	5.2	5.3	5.3	710	710	710	280	262	271	2	2	2	78	84	81
2	5.2	5.2	5.2	697	741	719	262	280	271	3	4	4	78	78	78
3	5.2	5.2	5.2	616	658	637	297	280	289	4	4	4	84	84	84
4	5.2	5.2	5.2	616	616	616	245	213	229	4	3	4	96	90	93
5	5.2	5.6	5.4	658	658	658	213	280	247	2	2	2	96	96	96
Ave.	5.2	5.3	5.3	659	677	668	259	263	261	3	3	3	86	86	86
No. 3—Old Cultivated soil															
1	5.5	5.5	5.5	455	455	455	280	262	271	3	4	4	114	114	114
2	5.5	5.4	5.5	473	473	473	280	245	262	4	4	4	114	108	111
3	5.5	5.5	5.5	445	445	445	280	280	280	6	7	7	120	120	120
4	5.5	5.4	5.5	490	445	467	315	297	306	7	6	7	126	120	123
5	5.6	5.5	5.6	574	532	553	262	262	262	5	6	6	132	132	132
Ave.	5.5	5.5	5.5	487	470	479	283	269	276	5	6	5	121	119	120

*Ammonium Acetate (pH 4.8) extracting solution used.

TABLE 3.—THE pH AND EASILY EXTRACTABLE NUTRIENT LEVELS OBTAINED ON 5 CONSECUTIVE DAYS FOR A TIFTON FINE SANDY LOAM SOIL.*

Days	pH			CaO lbs/A			MgO lbs/A			P_2O_5 lbs/A			K_2O lbs/A		
	Duplicates			Duplicates			Duplicates			Duplicates			Duplicates		
	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.
No. 4—Virgin soil															
1	5.0	5.4	5.2	175	175	175	72	82	77	4	4	4	72	72	72
2	5.1	5.2	5.2	168	168	168	72	72	72	6	4	5	72	66	69
3	5.1	5.4	5.3	226	187	207	127	101	114	3	4	4	78	78	78
4	4.9	5.1	5.0	148	148	148	82	72	77	4	5	5	72	72	72
5	5.1	5.3	5.2	187	148	167	82	91	87	6	6	6	84	84	84
Ave.	5.0	5.3	5.2	181	165	173	87	84	85	5	5	5	76	74	75
No. 5—Young Cultivated or Pasture soil															
1	6.4	6.2	6.3	665	665	665	72	82	77	11	12	12	368	368	368
2	6.9	6.3	6.6	1060	1060	1060	82	82	82	8	9	9	347	340	344
3	6.4	6.1	6.3	700	658	679	82	91	87	13	8	11	340	347	344
4	6.4	6.2	6.3	618	658	638	91	91	91	10	8	9	347	340	344
5	6.5	6.1	6.3	700	658	679	63	72	68	10	9	10	361	354	358
Ave.	6.5	6.2	6.4	749	740	744	78	84	81	10	9	10	353	350	351
No. 6—Old Cultivated soil															
1	6.0	6.1	6.1	845	845	845	127	153	140	67	67	67	291	291	291
2	6.0	6.0	6.0	876	921	899	127	153	140	68	72	70	304	297	301
3	6.0	6.1	6.1	965	912	938	153	153	153	67	63	65	297	304	301
4	6.0	6.0	6.0	912	912	912	140	140	140	67	67	67	297	304	301
5	6.0	6.1	6.1	1018	1072	1045	127	140	133	72	68	70	347	340	344
Ave.	6.0	6.1	6.0	923	932	928	135	148	141	68	68	68	307	307	307

*Ammonium Acetate (pH 4.8) extracting solution used.

TABLE 4.—THE pH AND EASILY EXTRACTABLE NUTRIENT LEVELS OBTAINED ON 5 CONSECUTIVE DAYS FOR A LAKELAND FINE SAND SOIL.*

Days	pH Duplicates 1	pH Duplicates 2	pH Ave.	CaO lbs/A Duplicates 1	CaO lbs/A Duplicates 2	CaO lbs/A Ave.	MgO lbs/A Duplicates 1	MgO lbs/A Duplicates 2	MgO lbs/A Ave.	P_2O_5 lbs/A Duplicates 1	P_2O_5 lbs/A Duplicates 2	P_2O_5 lbs/A Ave.	K_2O lbs/A Duplicates 1	K_2O lbs/A Duplicates 2	K_2O lbs/A Ave.
No. 7—Virgin soil															
1	5.3	5.5	5.4	70	70	70	23	16	20	34	36	35	24	24	24
2	5.3	5.3	5.3	84	84	84	16	16	16	33	33	33	24	24	24
3	5.3	5.5	5.4	70	70	70	16	16	16	34	36	35	30	20	30
4	5.3	5.3	5.3	70	70	70	16	16	16	36	34	35	30	24	27
5	5.3	5.3	5.3	70	70	70	16	16	16	37	37	37	30	30	30
Ave.	5.3	5.4	5.3	73	73	73	17	16	17	35	35	35	28	26	27
No. 8—Young Cultivated or Pasture soil															
1	5.5	5.8	5.6	245	245	245	127	140	134	34	33	34	36	36	36
2	5.6	5.7	5.6	294	294	294	127	140	134	34	33	34	30	36	33
3	5.6	5.8	5.7	266	266	266	114	114	114	33	31	32	36	36	36
4	5.7	5.7	5.7	266	311	288	140	140	140	36	36	36	36	36	36
5	5.7	5.9	5.8	311	266	288	101	114	108	36	34	35	42	42	42
Ave.	5.6	5.8	5.7	276	276	276	122	130	126	35	33	34	36	37	37
No. 9—Old Cultivated soil															
1	5.7	6.0	5.8	210	210	210	23	23	23	38	36	37	60	60	60
2	5.7	5.8	5.8	210	252	231	38	38	38	34	31	33	60	60	60
3	5.7	5.9	5.8	227	227	227	46	38	42	38	36	37	60	60	60
4	5.7	5.8	5.8	187	227	207	23	31	27	36	38	37	66	66	66
5	5.7	5.7	5.7	227	227	227	38	38	38	39	37	38	72	72	72
Ave.	5.7	5.8	5.8	212	228	220	34	34	34	37	36	36	64	64	64

*Ammonium Acetate (pH 4.8) extracting solution used.

TABLE 5.—THE pH AND EASILY EXTRACTABLE NUTRIENT LEVELS OBTAINED ON 5 CONSECUTIVE DAYS FOR A LEON FINE SAND SOIL.*

Days	pH Duplicates 1	pH Duplicates 2	pH Ave.	CaO lbs/A Duplicates 1	CaO lbs/A Duplicates 2	CaO lbs/A Ave.	MgO lbs/A Duplicates 1	MgO lbs/A Duplicates 2	MgO lbs/A Ave.	P_2O_5 lbs/A Duplicates 1	P_2O_5 lbs/A Duplicates 2	P_2O_5 lbs/A Ave.	K_2O lbs/A Duplicates 1	K_2O lbs/A Duplicates 2	K_2O lbs/A Ave.
No. 10—Virgin soil															
1	4.7	4.7	4.7	287	287	287	91	101	96	4	6	5	30	30	30
2	4.6	4.6	4.6	294	294	294	91	114	102	4	6	5	30	30	30
3	4.5	4.7	4.6	311	311	311	101	127	114	7	6	6	36	36	36
4	4.6	4.6	4.6	311	311	311	144	91	118	6	7	6	42	42	42
5	4.6	4.3	4.4	266	266	266	101	101	101	7	7	7	36	42	39
Ave.	4.6	4.6	4.6	294	294	294	106	107	106	6	6	6	35	36	35
No. 11—Young Cultivated or Pasture soil															
1	5.0	5.2	5.1	581	539	560	72	82	77	9	10	10	114	114	114
2	5.0	5.0	5.0	607	562	584	53	63	58	9	11	10	120	114	117
3	5.0	5.1	5.0	532	532	532	63	63	63	8	11	10	114	114	114
4	5.0	5.0	5.0	574	532	553	82	91	86	6	9	8	126	126	126
5	5.0	5.1	5.0	490	490	490	46	53	50	8	10	9	120	120	120
Ave.	5.0	5.1	5.0	557	531	544	63	70	67	8	10	9	119	118	118
No. 12—Old Cultivated soil															
1	5.7	5.7	5.7	2518	2455	2486	166	153	160	83	78	80	155	152	154
2	5.7	5.6	5.6	2364	2424	2394	140	182	161	76	72	74	145	145	145
3	5.7	5.6	5.6	2559	2500	2530	153	166	160	76	76	76	152	152	152
4	5.6	5.6	5.6	2500	2559	2530	213	182	198	78	78	78	158	158	158
5	5.7	5.6	5.6	2679	2789	2734	140	127	134	88	90	89	165	172	168
Ave.	5.7	5.6	5.6	2524	2545	2535	162	162	162	80	79	80	155	156	155

*Ammonium Acetate (pH 4.8) extracting solution used.

TABLE 6.—THE pH AND EASILY EXTRACTABLE NUTRIENT LEVELS OBTAINED ON 5 CONSECUTIVE DAYS FOR A LAKELAND FINE SAND SOIL.*

Days	pH			CaO lbs/A			MgO lbs/A			P_2O_5 lbs/A			K_2O lbs/A		
	Duplicates			Duplicates			Duplicates			Duplicates			Duplicates		
	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.	1	2	Ave.
No. 13—Virgin soil															
1	5.3	6.0	5.6	70	70	70	16	16	16	6	5	5	18	18	18
2	5.2	5.5	5.3	84	84	84	8	16	12	4	6	5	18	18	18
3	5.3	6.0	5.6	70	70	70	23	31	27	5	4	4	24	24	24
4	5.2	5.4	5.3	70	70	70	38	31	34	6	6	6	24	24	24
5	5.2	5.6	5.4	70	70	70	16	23	20	7	8	7	18	18	18
Ave.	5.2	5.7	5.5	73	73	73	20	23	22	6	6	6	20	20	20
No. 14—Young Cultivated or Pasture soil															
1	6.6	6.7	6.6	800	800	800	262	262	262	14	17	15	24	24	24
2	6.7	6.6	6.6	921	921	921	297	297	297	17	17	17	24	24	24
3	6.6	6.6	6.6	859	859	859	297	297	297	15	16	15	30	30	30
4	6.6	6.5	6.5	912	912	912	332	297	314	17	17	17	24	30	27
5	6.6	6.7	6.6	965	965	965	297	332	314	18	17	17	24	24	24
Ave.	6.6	6.6	6.6	891	891	891	297	297	297	16	17	16	25	26	26
No. 15—Old Cultivated soil															
1	7.1	7.1	7.1	2081	2022	2051	594	633	613	68	72	70	78	84	81
2	7.2	7.1	7.1	1959	1959	1959	594	594	594	70	72	71	66	66	66
3	7.1	7.0	7.0	2071	2015	2043	673	633	653	72	70	71	72	72	72
4	7.2	7.0	7.1	1959	2015	1987	594	673	633	68	67	67	66	66	66
5	7.2	7.5	7.3	2015	2015	2015	594	534	564	74	72	73	66	72	69
Ave.	7.2	7.1	7.1	2017	2005	2011	610	613	612	70	71	70	70	72	71

*Ammonium Acetate (pH 4.8) extracting solution used.

TABLE 7.—THE pH AND EASILY EXTRACTABLE NUTRIENT LEVELS OBTAINED ON 5 CONSECUTIVE DAYS FOR A BLANTON FINE SAND SOIL.*

Days	pH Duplicates 1	pH Duplicates 2	pH Ave.	CaO lbs/A Duplicates 1	CaO lbs/A Duplicates 2	CaO lbs/A Ave.	MgO lbs/A Duplicates 1	MgO lbs/A Duplicates 2	MgO lbs/A Ave.	P_2O_5 lbs/A Duplicates 1	P_2O_5 lbs/A Duplicates 2	P_2O_5 lbs/A Ave.	K_2O lbs/A Duplicates 1	K_2O lbs/A Duplicates 2	K_2O lbs/A Ave.
No. 16—Virgin soil															
1	5.5	5.9	5.7	329	329	329	46	46	46	31	32	31	30	30	30
2	5.5	5.6	5.5	383	428	405	38	38	38	30	31	30	30	24	37
3	5.4	5.9	5.6	355	311	333	31	38	34	28	30	29	30	30	30
4	5.4	5.6	5.5	311	355	333	63	53	58	29	30	29	30	30	30
5	5.4	5.8	5.6	311	311	311	38	38	38	32	32	32	30	30	30
Ave.	5.4	5.8	5.6	338	347	342	43	43	43	30	31	30	30	29	29
No. 17—Young Cultivated or Pasture soil															
1	6.0	6.1	6.0	845	845	845	245	262	253	68	70	69	84	90	87
2	6.1	6.0	6.0	876	876	876	262	297	279	67	63	65	81	78	81
3	6.0	6.2	6.1	806	859	832	297	262	279	63	67	65	90	90	90
4	6.0	6.0	6.0	806	806	806	245	262	253	65	63	64	81	84	81
5	6.1	6.3	6.2	859	806	832	245	262	253	67	68	67	81	84	84
Ave.	6.0	6.1	6.1	838	838	838	259	269	264	66	66	66	85	85	85
No. 18—Old Cultivated soil															
1	6.0	6.1	6.0	1119	1119	1119	213	213	213	101	104	102	152	158	155
2	6.0	6.0	6.0	1108	1156	1132	213	213	213	99	101	100	145	138	141
3	5.9	6.1	6.0	1125	1072	1098	245	229	237	93	93	93	145	145	145
4	5.9	6.0	5.9	1178	1125	1151	297	262	279	101	101	101	145	145	145
5	6.0	6.2	6.1	1125	1125	1125	262	229	245	101	101	101	152	158	155
Ave.	6.0	6.1	6.0	1131	1119	1125	246	229	238	99	100	99	148	149	148

*Ammonium Acetate (pH 4.8) extracting solution used.

TABLE 8.—THE AVERAGE pH VALUES OBTAINED FOR EACH SOIL.

Soil Type	Soil No.	pH				
		Average by Weeks				
		1	2	3	4	Ave.
Ruston fsl	1	5.4	5.5	5.5	5.4	5.4
	2	5.3	5.2	5.2	5.2	5.2
	3	5.5	5.4	5.4	5.4	5.4
Tifton fsl	4	5.2	5.0	5.1	5.0	5.1
	5	6.4	6.4	6.3	6.4	6.4
	6	6.0	6.0	6.0	6.0	6.0
Lakeland fs	7	5.3	5.2	5.2	5.2	5.2
	8	5.7	5.7	5.7	5.7	5.7
	9	5.8	5.7	5.7	5.7	5.7
Leon fs	10	4.6	4.6	4.6	4.6	4.6
	11	5.0	5.0	5.0	5.0	5.0
	12	5.6	5.6	5.6	5.6	5.6
Lakeland fs	13	5.5	5.2	5.3	5.3	5.3
	14	6.6	6.6	6.5	6.6	6.6
	15	7.1	7.1	7.0	7.0	7.0
Blanton fs	16	5.6	5.4	5.5	5.4	5.5
	17	6.1	6.0	6.0	6.0	6.0
	18	6.0	6.0	6.0	5.9	6.0

Each value represents an average of duplicate determinations made on five successive days.

TABLE 9.—THE AVERAGE CaO VALUES OBTAINED FOR EACH SOIL.

Soil Type	Soil No.	CaO lbs/A				
		Average by Weeks				
		1	2	3	4	Ave.
Ruston fsl	1	247	184	294	219	236
	2	668	602	732	668	667
	3	479	400	518	452	462
Tifton fsl	4	173	179	164	138	163
	5	744	644	691	673	688
	6	928	904	944	958	934
Lakeland fs	7	73	36	80	50	60
	8	276	209	287	227	250
	9	220	191	343	236	248
Leon fs	10	294	292	339	306	308
	11	544	502	596	549	548
	12	2535	2537	2510	2536	2529
Lakeland fs	13	73	66	92	38	67
	14	891	872	885	884	883
	15	2011	2171	2151	2171	2126
Blanton fs	16	342	318	374	324	340
	17	838	936	894	821	872
	18	1125	1059	1161	1259	1151

Each value represents an average of duplicate determinations made on five successive days.

TABLE 10.—THE AVERAGE MGO VALUES OBTAINED FOR EACH SOIL.

Soil Type	Soil No.	MgO lbs/A Average by Weeks 1	2	3	4	Ave.
Ruston fsl	1	143	122	144	121	133
	2	261	234	256	232	246
	3	276	271	299	253	275
Tifton fsl	4	85	79	86	70	80
	5	81	59	81	62	71
	6	141	110	145	110	127
Lakeland fs	7	17	20	21	14	18
	8	126	108	137	113	121
	9	34	34	40	16	31
Leon fs	10	106	72	111	81	92
	11	67	59	59	53	59
	12	162	134	153	124	143
Lakeland fs	13	22	15	18	11	17
	14	297	260	280	273	277
	15	612	633	657	612	628
Blanton fs	16	43	38	48	33	41
	17	264	231	254	225	244
	18	238	183	237	210	217

Each value represents an average of duplicate determinations made on five successive days.

TABLE 11.—THE AVERAGE P_2O_5 VALUES OBTAINED FOR EACH SOIL.

Soil Type	Soil No.	P_2O_5 lbs/A Average by Weeks 1	2	3	4	Ave.
Ruston fsl	1	3	4	3	3	3
	2	3	4	3	2	3
	3	5	6	6	5	6
Tifton fsl	4	5	5	4	4	5
	5	10	11	10	10	10
	6	68	65	70	64	67
Lakeland fs	7	35	32	35	30	33
	8	34	32	35	32	33
	9	36	32	35	32	34
Leon fs	10	6	7	7	7	7
	11	9	8	9	9	9
	12	80	74	81	76	78
Lakeland fs	13	6	6	6	5	6
	14	16	17	17	17	17
	15	70	69	72	73	71
Blanton fs	16	30	26	29	26	28
	17	66	65	68	64	66
	18	99	87	102	90	95

Each value represents an average of duplicate determinations made on five successive days.

TABLE 12.—THE AVERAGE K_2O VALUES OBTAINED FOR EACH SOIL.

Soil Type	Soil No.	K_2O lbs/A Average by Weeks 1	2	3	4	Ave.
Ruston fsl	1	123	131	142	139	134
	2	86	98	95	99	95
	3	120	127	132	129	127
Tifton fsl	4	75	82	74	76	77
	5	351	369	355	358	358
	6	307	310	312	304	308
Lakeland fs	7	27	28	29	36	30
	8	37	40	44	47	42
	9	64	61	65	64	64
Leon fs	10	35	39	40	41	39
	11	118	121	127	123	122
	12	155	155	156	155	155
Lakeland fs	13	20	21	23	21	21
	14	26	25	25	26	26
	15	71	79	77	81	77
Blanton fs	16	29	34	32	34	32
	17	85	83	86	87	85
	18	148	150	158	158	154

Each value represents an average of duplicate determinations made on five successive days.

TABLE 13.—THE pH AND NUTRIENT LEVELS OBTAINED FROM ALL DETERMINATIONS.

Soil Type	Soil* No.	pH	CaO lbs/A	MgO lbs/A	P_2O_5 lbs/A	K_2O lbs/A
Ruston fsl	1	5.4	236	133	3	134
	2	5.2	667	246	3	95
	3	5.4	462	275	6	127
Tifton fsl	4	5.1	163	80	4	77
	5	6.4	688	71	10	358
	6	6.0	934	127	67	308
Lakeland fs	7	5.2	60	18	33	30
	8	5.7	250	121	33	42
	9	5.7	248	31	34	64
Leon fs	10	4.6	308	92	7	39
	11	5.0	548	59	9	122
	12	5.6	2529	143	78	155
Lakeland fs	13	5.3	67	17	6	21
	14	6.6	883	277	17	26
	15	7.0	2126	628	71	77
Blanton fs	16	5.5	340	41	28	32
	17	6.0	872	244	66	85
	18	6.0	1151	217	95	154

Each value represents an average of duplicate determinations made on twenty different days.

*The samples are listed under each soil type in the following order: Virgin soil, Young cultivated or pasture soil and Old cultivated soil.

TABLE 14.—SOIL ANALYSIS VALUES OBTAINED BY DAYS FOR THE 4 WEEKS REGARDLESS OF SOIL FERTILITY LEVEL.

Soil Type	Days	pH	CaO lbs/A	MgO lbs/A	P_2O_5 lbs/A	K_2O lbs/A
Ruston fsl	1	5.4	457	224	4	116
	2	5.4	467	223	3	117
	3	5.4	451	220	5	117
	4	5.4	451	217	4	119
	5	5.4	450	204	3	123
	Ave.	5.4	455	218	4	118
Tifton fsl	1	5.8	594	92	27	250
	2	5.9	642	94	27	244
	3	5.8	563	95	28	244
	4	5.8	575	91	27	248
	5	5.8	500	89	27	251
	Ave.	5.8	595	92	27	248
Lakeland fs	1	5.6	185	62	34	45
	2	5.6	199	61	32	44
	3	5.6	172	55	33	45
	4	5.6	174	54	34	45
	5	5.5	199	50	33	48
	Ave.	5.6	186	56	33	45
Leon fs	1	5.1	1112	99	31	104
	2	5.1	1132	106	30	105
	3	5.1	1122	93	32	103
	4	5.1	1130	104	30	107
	5	5.1	1143	90	32	108
	Ave.	5.1	1128	98	31	105
Lakeland fs	1	6.3	1022	306	32	42
	2	6.3	1023	310	28	40
	3	6.3	1041	307	32	40
	4	6.3	1018	307	31	41
	5	6.3	1022	302	32	42
	Ave.	6.3	1025	307	31	41
Blanton fs	1	5.9	770	165	64	92
	2	5.8	841	167	63	89
	3	5.8	771	166	62	90
	4	5.8	760	168	63	88
	5	5.8	794	169	62	92
	Ave	5.8	788	167	63	90

Each value represents an average of duplicate determinations made on five days of four different weeks.

tions in individual determinations have disappeared. The maximum variations from the mean are as follows: ±0.1 pH unit, +53 and −95 pounds of CaO per acre, +8 and −14 pounds of MgO per acre, +1 and −3 pounds of P_2O_5 per acre and +5 and −4 pounds of K_2O per acre. The calcium variation of 95 pounds of CaO per acre represents only a 16% variation for the particular soil.

The variations obtained in the analytical data include all errors caused by sampling, methods, instruments and operators. The methods and instruments have certain limitations and the data given in Table 15 illustrate this point. All values given in the table were taken from standard curves obtained on the different instruments for the particular nutrient

TABLE 15.—VALUES EQUIVALENT TO ONE PERCENT TRANSMISSION AT DIFFERENT CONCENTRATIONS OBTAINED FROM STANDARD CURVES.

CaO*		MgO*		K_2O*	
lbs/A	1% T = lbs/A	lbs/A	1% T = lbs/A	lbs/A	1% T = lbs/A
40-300	42	-	----	0-35	5
340-740	45	-	----	40-95	5
786-1204	46	8-16	8	102-156	6
1250-1680	47	23-101	8	162-220	6
1728-2854	54	114-245	13	228-298	7
2312-2854	60	262-443	18	306-368	7
2920-3512	65	473-791	32	375-446	8
Ave.	51		16		6

*The calcium, magnesium and potassium data obtained from this study read from 4-58, 30-70 and 6-60% transmission, respectively.

listed. It is usually impractical in routine soil analysis work to adjust the concentration of the leachate so that the percent transmission of light, as shown by the galvanometer on the instrument, will fall in the most desirable part of the standard curve. This part of the curve is from about 30 to 80% transmission. The range in concentration of the solutions used for making the standard curves cover a sufficient range for the majority of the determinations to be made. Any samples falling at the extreme ends of the standard curve usually may be classified as being either very low or very high. For the above reasons, all determinations for this study were made in a routine manner and using the same range of standards normally employed. Therefore, the range in percentage transmission for CaO was 4-58 percent, MgO was 30-70 percent and K_2O 6-60 percent. A difference of one percent transmission in reading the instrument for calcium resulted in a variation of from 42 to 65 pounds of CaO per acre. Since the readings normally would be made to only plus or minus one percent transmission the values would double. The range is due to the concentration, or part of the standard curve, of which the reading is made. A similar variation of one percent transmission for magnesium could be responsible for as much as 32 and as little as 8 pounds of MgO per acre. The numerical value obtained from the standard curve for the potassium was much less, being 5 to 8 pounds of K_2O per acre, but could still be very important in many cases.

A straight line should always be obtained for the phosphorus standard curve since the determination follows Beer's Law. Therefore, each one percent change in transmission was equivalent to approximately one pound of P_2O_5 per acre.

Reproducibility of plus or minus one percent transmission is the best that can be expected of most instruments by any operator. When this is considered, most of the apparent variation in the data obtained by this study is eliminated. The remaining variation, or error, was due to heterogenity of the soil samples, moisture affecting the sensitivity of the instruments, contamination and other factors.

The use of percentages in reporting variations in soil test data may also be misleading unless the size of the values involved are known. In the

case of phosphorus a variation of 1 pound from the mean of 5 pounds represents a 20% variation. To obtain a 20% variation from a mean of 2000 pounds of calcium would require a variation of 400 pounds.

SUMMARY AND CONCLUSIONS

A study was initiated to determine the variations in analytical data that may be expected in the operation of the Soil Testing Laboratory. Eighteen soil samples were collected from various areas of the state to represent some of the more important mineral soil types. They were sub-sampled and analyzed in the laboratory according to routine procedures for 5 successive days of four different weeks. The pH, calcium, magnesium, phosphorus and potassium determinations were made in duplicate on each subsample for the twenty days.

The maximum numerical variation from the mean of the average for duplicate determinations for the first week was: pH—0.2 unit, CaO—316 pounds per acre, MgO—48 pounds per acre, P_2O_5—9 pounds per acre, and K_2O—37 pounds per acre. When the data were averaged for each week and compared to the mean for the four weeks the variations were reduced considerably. The variations were then: pH—0.2 unit, CaO—115 pounds per acre, MgO—34 pounds per acre, P_2O_5—8 pounds per acre, and K_2O—11 pounds per acre.

All variations obtained in the soil analysis data were not necessarily due to errors in the determination but rather because of its limitations. The average effect of a one percent transmission variation for the different determinations was 51 pounds of CaO per acre, 16 pounds per acre of MgO, 6 pounds of K_2O per acre and 1 pound of P_2O_5 per acre.

The reproducibility for the instruments is usually about plus or minus one percent transmission. In most cases this accounted for the largest variation in the analytical data. Other factors that may have caused error were heterogenity and contamination of the samples.

ACKNOWLEDGEMENTS

Authors wish to express their appreciation to Mr. H. L. Carver and others of the Soil Test Lab staff for their valued assistance in making this study.

LITERATURE CITED

1. Breland, Herman L. Methods of Analysis used in Soil Testing. Dept. of Soils Mimeo Report No. 58-3, 1957.
2. Fitts, J. W. and W. L. Nelson. The Determination of Lime and Fertilizer Requirements of Soils Through Chemical Tests. Advances in Agronomy 8:241-282. 1956. Academic Press, Inc., Publishers, New York.
3. Morgan, M. F. Chemical Soil Diagnosis by the Universal Soil Testing System. Conn. Agric. Exp. Station. Bulletin 450, 1941.
4. Southern Regional Soil Test Work Group. Proceedings of the 4th Southern Regional Soil Test Work Group Meeting. June, 1958.
5. Truog, E. The Determination of the Readily Available Phosphorus of Soil. Jour. Amer. Soc. Agronomy 22:874, 1930.

Status and Outlook of the State Soil Testing Program

M. O. WATKINS[1]

In delineating the scope of my summary discussion on soil testing, I have interpreted the "State Soil Testing Program" to mean the so-called service type work carried on by the Extension and Experiment Station systems of the State. I shall direct my remarks primarily toward the soil testing work of the Extension Service. Perhaps a bit of history elaborating on Dr. NeSmith's remarks on the policy decisions affecting Extension's role in soil testing would clarify our present situation.

Back in 1958 the Directors of the Agricultural Experiment Stations and Agricultural Extension Service discussed the soil testing work then carried on by the Station at Gainesville with those responsible for determining policies. Included among these policy makers were the Provost for Agriculture, the President of the University of Florida, the Florida Agricultural Council, the Legislature, the Board of Control and others.

Basically the problem at that time was that the service type soil testing work, which was then a function of the Soils Department of the Agricultural Experiment Stations, had grown over the years to a point where it was interfering with research work and something of a burden to the Station system. The question to be resolved was what to do about it. Should it be continued in the Experiment Station? Should it be turned over to some other state agency? Should it be dropped entirely as a program financed with public funds? Or should the Extension Service assume responsibility for it? The decision as Dr. NeSmith indicated was finally made by the 1959 Legislature and placed responsibility for the work with the Extension Service. Under the new arrangement all soil testing work, both service and research, is handled by Extension. The Station reimburses Extension for the research tests. In this the research people work closely with Extension to be sure that each benefits from the work of the other.

Extension's soil testing program at Gainesville has two major objectives. The first is to provide county agents with an additional diagnostic tool in determining the answers to nutritional problems in the production of fruit, nut and vegetable crops. The second is to promote and encourage more efficient use of fertilizers by providing growers with fertilizer recommendations backed up by soil tests. All work is carried on with and through county agents.

The agents in central and south Florida use soil testing almost exclusively for diagnostic purposes. The reasons for this are twofold. First, citrus and vegetable growers normally use optimum amounts of fertilizer and sometimes more on their crops, since fertilizer is a small part of a high cost operation. Second, soil testing service is usually readily available to growers by private laboratories or by fertilizer companies. Extension has no desire to duplicate or compete with private enterprise.

In north and west Florida the exact opposite is true. Industry soil testing is not generally available and growers traditionally have used far less fertilizer than soil tests would indicate desirable. Extension is consequently operating under two entirely different situations.

[1]Director, Agricultural Extension Service, University of Florida, Gainesville.

As we look ahead it is probable that the number of soil samples run by Extension will continue to increase in the foreseeable future. As agriculture becomes more and more specialized new additions to county Extension staffs are specialized in their functions. Many are already well-trained in soils, and no doubt more will be in the future. These men will make increasing use of soil testing, both for diagnostic purposes as well as to encourage more economic use of fertilizers.

In connection with the latter, there is a real need to increase fertilizer consumption in the general crops area of northwest Florida, to speed the economic development of these areas. Income from agriculture can be greatly stepped up in many cases by more optimum use of plant food. An example of just how quickly a county can feel the impact of a more adequate fertilization program can be seen in the results of the Rural Development work in Suwannee County. Here soil tests showed the need for a greatly expanded liming program. With help from A.S.C. in the form of a special liming and cover crop practice, corn yields have gone up sharply to a present estimated average of thirty bushels per acre. The result has been the erection of a corn drying and storage facility which provides jobs for more people. This has meant increased net income to farmers from corn crops. The Rural Development Program has spread to a total of five counties and soil testing is helping to point the way to increased profits in most.

One very important function of the state soil testing laboratory at Gainesville is that of correlating soil tests with crop response which becomes available through test data. As Dr. NeSmith indicated, we are very short on these data at present. I indicated earlier that Research and Extension people were working together. One function of their joint efforts is to provide calibrated data. County Agents who conduct demonstrations to evaluate soil testing will be able to contribute more data for calibration purposes. Soil testing will become of increasing economic importance to growers as these data provide more definite information.

Another important role which the soil testing work at Gainesville is beginning to fill is that of a base or control laboratory for other laboratories in the state. Dr. NeSmith mentioned the survey of laboratories doing soil testing work. Our aim is to bring about a closer cooperation between the various concerns doing soil testing, and perhaps to establish minimum requirements for soil testing. This function also extends to standardizing techniques and methods, which in turn will lead to better grower understanding of soil testing as well as better service by all laboratories.

As to the further consolidation of soil testing within the Extension Service and between Extension and the Experiment Stations, we certainly do not have a blue print to follow at this point. The work over the years which the Everglades Experiment Station at Belle Glade has done on muck soils has resulted in building up a body of information which is invaluable to growers and which I am sure they would not want to see curtailed in any way. Many county agents run pH tests in their offices and there are complete soil testing laboratories run by county agents in Escambia and Dade Counties. The latter will no doubt continue for some time to come. The Dade County lab has been of much help to growers in determining the extent of intrusion of salt water into farm lands. Both of these labs are about equal distance from Gainesville, and emphasize the

distance factor in the time involved from taking the sample to availability of results.

Our hope is now that certain policies with respect to soil testing have been evolved. We can make the laboratory at Gainesville operate fast enough, efficiently enough, and accurately enough to serve the state's needs in the areas in which we function. Through the continued close cooperation between Extension, Research and Industry our combined efforts should help Florida growers to compete successfully with the rest of the nation in production efficiency.

BANQUET AND BUSINESS MEETING

The Annual Business Meeting of the Society immediately followed the Monday evening meeting (Nov. 28) of the first day of the sessions which were held in the auditorium of Hotel Fort Harrison at Clearwater. It was called to order by President J. R. Henderson and the usual routine of business taken up, including the reports of committees and of the Secretary-Treasurer, particularly as the latter pertained to membership, publication of the Proceedings and the financial status of the organization.

A particularly happy occasion was developed after the annual banquet on Tuesday evening and immediately following the after-dinner address of Dr. George D. Scarseth who spoke on "The High Road in Crop Production." The full text of Dr. Scarseth's address will be found on pp. 15-17 where it is associated with his nomination and election to Honorary Lifetime Membership in the Society. Reference is to the nomination and election to Honorary Lifetime Membership in the Society of an additional group of ten outstanding workers in the Soil and Plant Sciences especially in the spirit of marking and even celebrating the arrival of the organization's 20th anniversary.

It is regrettable that the joy of the planning for this occasion was greatly dampened by the inability of one of the nominees to accept due to circumstances far beyond his control—in fact to circumstances that are very dark indeed and all too close even for our national comfort, to those who are trying to reshape the world at the present time. We are truly fortunate, however, in finding a worthy alternate to the end that the published record is complete and the Society honored in its turn by the acceptance of each member of this group.

MEMBERSHIP

There is little that is new to report in the matter of membership trends except to note that a considerable number of 1959 members are still in arrears for 1960. This may be adjudged due, in part at least, to the impact of the increase in dues from $1.00 to $3.00 for the year beginning with 1960, this latter sum, of course, to include a copy of the Proceedings as in the past. With other thoughts such as oversight, absence from State and country on a foreign tour of duty or even miscarriage of the mails up to two or three times in succession, at least in the case of what might be regarded as the most likely among this group for the rehabilitation of their membership will be selected to receive, at the proper time, further notice as to their dues status, advice as to the time and place of the 21st annual meeting as well as the content of the program and a final inquiry as to whether they do or do not wish to receive a copy of Proceedings Volume 20. It should, of course be noted that many new members at both the Annual and Sustaining level have been added to the rolls during the year which replace to quite a substantial extent those who, such as the above, have been lost during the period covered by this or the previous report. The trend of this balance is well revealed in the usual table of membership distribution that follows which shows the relationship of members not only as to geographical distribution for the two years indicated but also within the two principal membership groups for both years under the geographical conditions of distribution indicated.

Geographical Distribution of Membership

	Annual		Sustaining		Honorary Life		Total	
	1959	1960	1959	1960	1959	1960	1959	1960
Florida	545	520	85	78	1	2	631	600
U.S. other than Florida	175	166	35	38	7	14	217	218
Caribbean	81	77	6	10	1	3	88	90
Foreign	42	39	6	5	1	1	49	45
Total	843	802	132	131	10	20	985	953

REPORT OF TREASURER

As has been practiced in the past, with the approval of the Executive Committee, the financial report of the Society, as published herewith is made to cover the calendar year rather than close at the time of any particular annual meeting. This is for the obvious advantages that already have been quite fully discussed.

Statement of Receipts & Disbursements
Jan. 1, 1960 thru Dec. 31, 1960

Cash in bank January 1, 1960		
Florida National Bank	440.08	
Everglades Federal Savings & Loan Company	3,134.43	
		$3,574.51
Receipts:		
Regular dues collected	2,131.88	
Sustaining dues collected	2,459.00	
Proceedings sold	166.00	
Postage Refunds	2.28	
Registration at annual meeting	225.77*	
		4,984.93
Monies to be accounted for		8,559.44
Disbursements:		
Office supplies	151.31	
Postage	367.95	
Publications (Vol. 19)	2,410.77**	
Expenses of annual meeting	219.81	
		3,149.84
Cash in bank Dec. 31, 1960		
Florida National Bank	1,252.29	
Everglades Federal Savings & Loan Co.	4,157.31	
		5,409.60
Monies accounted for		$8,559.44

*This is not a true figure of registrations ($258.00) as deduction was made from this for certain banquet costs.

**This is a partial payment of a total of $4,801.55 cost for printing Volume 19. Final payment will show in 1961 final statement.

PUBLICATION

It is, a bit painful, of course, from the standpoint of the Society's finances to again state that this volume "has exceeded all earlier volumes in size and, of course, in cost of publication." However, it is fully believed that the obvious value of the additional material presented, since it represents only a natural growth of participating interest in the forum of the Society, fully justifies this cost.

It is with real regret that we report Dr. Steiner's inability to complete his valuable paper on certain phases of tropical nematology and get it to us in time for inclusion in this volume. It will be recalled that it should have been published with its companion papers and their introduction on this general subject that are to be found on pages 428-463 of Proc. Vol. 19. Since it has been a long time plan to publish this whole series as a reprint from the Proceedings of the Society we can only continue to hope for its completion in due course. The value of making such a record more readily accessible to agricultural workers in the tropics as well as other parts of the world will indeed be very great, a fact that is attested to by the numerous inquiries already in hand regarding the prospective availability of this material.

REPORT OF COMMITTEES

NOMINATING COMMITTEE

This committee, which consisted of Dr. Nathan Gammon, Jr., Dr. E. L. Spencer and Dr. W. T. Forsee, Jr., with the latter acting as chairman, had been appointed by President Henderson well in advance of the meetings and charged with presenting, at the proper time, one or more carefully selected candidates for the office of Vice President of the Society, the only elective position to be filled each year. Upon call for report the committee offered in nomination as an only candidate the name of Dr. William G. Blue, Associate Biochemist, Soils Department, College of Agriculture, Gainesville. There being no further nominations offered from the floor, the Chairman of the Nominating Committee moved the nominations be closed and the Secretary of the Society be instructed to cast a unanimous vote for Dr. Blue. In consequence of several prompt seconds and no question to the motion Dr. Blue became the new Vice President of the Society and, simultaneously, by force of precedent, the Chairman of the Program Committee for the coming year.

RESOLUTIONS COMMITTEE:

The Resolution of Sympathy read by the Secretary told of the loss by death of ten valued members of the Society during the year. The reading was followed by a brief period of silence at the request of the President. This resolution will be found published in full on page 427 of this volume.

NOMINATION AND ELECTION OF NEW LIFETIME MEMBERS

Just before the passing of the gavel, and as his last official act in office, President Henderson called for the reading of the names and addresses of the ten workers in the Soil and Plant Sciences who had been nominated by the Executive Committee for election as Honorary Lifetime Members.

This reading was immediately followed by a motion that all ten men be elected to Honorary Lifetime Membership in the Society as individuals and as a group and the Secretary be instructed to write each of the Society's action and of the honor the organization feels for their acceptance. The names listed below are as presented in the original list with the exception of that of Dr. P. H. Senn who had meantime retired from a lifetime of most creditable and constructive service in the Agronomy Department of the College of Agriculture and was used to replace that of the worker who eventually found that he was unable to accept for the good and sufficient reason referred to elsewhere in this report. By way of record a much too brief biographical sketch along with a small photograph of each is included at the front of the volume on pages 5-14. The names of the new members follow:

Mr. H. G. Clayton
Dr. H. K. Hayes
Dr. J. E. McMurtrey, Jr.
Dr. Knowles A. Ryerson
Dr. George D. Scarseth
Dr. P. H. Senn
Dr. T. R. Stanton
Dr. Emil Truog
Dr. G. Steiner
Mr. J. W. Turrentine

PASSING OF THE GAVEL

Immediately following the election of the group of Honorary Lifetime Members the gavel was passed by J. R. Henderson who was retired by this act to a position on the Executive Committee, to W. H. Chapman who simultaneously became the twenty-first President of the Society.

This phase of the Business Meeting of the Society was adjourned at 10:30 p.m.

MEETINGS OF THE EXECUTIVE COMMITTEE

A meeting of the Executive Committee was called by Chairman Chapman immediately following the Banquet with a full complement of attendance and the usual discussion of place of next meeting and plans for same after appointing R. V. Allison secretary-treasurer for another year.

The usual favor was found toward a central Florida location for the next meeting. Though no definite action was taken on this point, Tallahassee was favorably mentioned as affording an opportunity to become better acquainted with our new Commissioner of Agriculture as well as the Commissioner with the Society.

Favorable discussion was given to a member recommendation that more time be given on future programs for what are referred to as contributed papers and less to those planned and given as groups or as symposia.

It was decided that publication in the Proceedings of the Society could not be permitted without prior presentation of the work before a regular meeting of the Society.

Concern was expressed over the growing size of the Proceedings. Though several suggestions were considered as potential "cures" or efforts at same, including limitation of number of "free" pages with the author paying for the balance, in the instance of unduly long papers, no definite decision in the matter was reached in the course of the meeting.

Further and perhaps somewhat more favorable discussion was given to the setting up of what has been referred to in the past as Subject Matter Committees for purposes that have been lengthily discussed from time to time. Even though the number that is finding favor would appear to be about half of that usually brought to view, it would seem to suggest progress. The annual executive committee meeting was declared adjourned by the Chairman at 11:10 p.m.

At an interim meeting of the Committee held in Gainesville on April 10 discussion of some of the above questions was continued and the place and dates of the next meeting decided upon: Tallahassee, November 14, 15 and 16 with the Floridan Hotel as headquarters.

Particular thought in the discussion of the program itself at this time was given to the desirability of at least an outline review of the important water conservation work that is developing in what is known as Green Swamp and adjacent areas physiographically related to it in the Southwestern part of the State. A definite interest was evidenced in a brief report on this work already under way in setting up what might prove to be quite a large control district and the chairman of the program committee was advised to continue in the two or three contacts which had been initiated in this behalf.

RESOLUTION OF SYMPATHY

WHEREAS, death has taken from our rolls during the year the following esteemed members of the Society whose sincere and constructive interest in all aspects of the work will make their absence keenly felt for a long time to come,

NOW, THEREFORE, BE IT RESOLVED, that this expression of sorrow over this great loss and of sympathy to the immediate families of the deceased be spread upon the records of this Society and a copy of same be sent to the closest member of the family of each.

H. H. BENNETT, Falls Church, Virginia

HORACE A. BESTOR, Clewiston, Florida

ROGER W. BLEDSOE, Gainesville, Florida

JOHN K. MCPECK, Sebring, Florida

NATHAN MAYO, Tallahassee, Florida

W. C. OWEN, Clewiston, Florida

JOHN W. RANDOLPH, Belle Glade, Florida

F. C. SCHUBERT, Tampa, Florida

R. T. STAPP, Fellsmere, Florida

MARK R. TENNANT, Miami, Florida

J. RUSSELL HENDERSON

OFFICERS OF THE SOCIETY

1960 Retired

J. R. HENDERSON (Gainesville)	President
W. H. CHAPMAN (Quincy)	Vice President
P. H. SENN (Gainesville)	Past President
R. V. ALLISON (Belle Glade)	Secretary-Treasurer

SUSTAINING MEMBERS

1960

Allied Chemical Corp., Nitrogen Div., 40 Hector St., New York 16, N. Y.
Andrews, Charles O., Jr., 1216 E. Colonial Drive, Orlando
Ariens, Mando S., 109 Calumet St., Brillion, Wisc.
Arvida Greenhouses, Inc., P. O. Drawer 130, Miami 57
Bair, Dr. Roy A., 256 Alhambra Place, West Palm Beach
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